DESIGN AND FLAT-PATTERN DEVELOPMENT OF SHOE LAST SURFACES

A Thesis Submitted
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

March, 2000

by

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CERTIFICATE

It is certified that the work contained in the thesis entitled, "DESIGN AND FLAT-PATTERN DEVELOPMENT OF SHOE LAST SURFACES" by *Mr. Saurabh Vishal* has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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March, 2000

Dedicated
To
My Parents

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude towards my guide, Dr. S.G.Dhande for his invaluable guidance and help throughout my M.Tech programme both academically and personally. I am also indebted to him because he provided me with an excellent opportunity to work at CAD Lab IIT Kanpur, where I was able to work in leading areas such as CAD, Reverse Engineering, RP & RT. His positive attitude towards problems and his hard working nature has been a constant source of motivation for me.

I am grateful to Mr Sanat Agarwal for the fruitful technical discussions I had with him. My sincere thanks to Mr Puneet Tandon, Rahul, Siva Prasad and Siddharth Dubey who helped me at various stages of my work by providing excellent suggestions and support.

I am thankful to my CAD-P friends Swapnil, Sarvankumar, Deepak,Suresh, Anil, Yogesh and Prabhat for their timely help. My sincere thanks to Saurav, Nazan and Sheel for the assistance they provided me during the thesis work.

Off the lab I am specially thankful to Ashish, Subhendu, and Atul who shared my difficulties and stood by me during the hardtimes as well as during the happy moments.

I would like to thank to everyone in CAD-P Lab, Shri C.P. Singh, Shri S.C.Gupta, Shri Ravindra Srivastava, Shri BabuLal, Shri Sarju Prasad and others for their constant help in one way or other.

I wish to express my heartfelt thanks to my parents and my brother, for their endless love, encouragement and invaluable guidance.

Finally, I am grateful to the almighty for what I am today.

Saurabh Vishal

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ABSTRACT

Presently, designing and manufacturing of footwear is based on the skill and experience of the shoemaker. The accuracy and quality of the shoe, thus obtained, is dependent on shoemaker's capability and the tools used by him. Modern technologies such as CAD/CAM and Reverse Engineering have recently become very powerful and advanced. These technologies can be moulded appropriately for the optimal design and manufacturing of footwear.

A methodology for the development of a customized virtual 3D shoe last has been developed. The point data cloud of a foot is obtained at certain critical regions and set of certain crucial points are then obtained from it. A set of normalized cubic splines are constructed through these points. The designer has the facility to modify the shape of the curve according to his convenience through changes in magnitude of tangent vectors. Coon's bicubic surface patches with required continuity constraints (C^0 ,C^1) are then fitted on this curve-network. Variations in the shape of these surface patches can be done by the designer through changes in magnitudes of twist and tangent vectors.

The development of patterns for a particular style of shoe design has been dealt in this work. The requirement for this is the surface definition of the last. The last's surface definition can be obtained either by scanning an existing last or by creating a customized last to meet the requirements. On-screen designing of the shoe style is done directly on the last definition and the flat patterns for this particular style are obtained by development of various selected surface patches of the last.

A technique for flat pattern development of parametric 3D surfaces, leading to nondistorted texture mapping, has been described. The technique is based on the results

of differential geometry, more precisely on the notion of "geodesic curvature". Isoparametric curves of the surface are mapped in a constructive way, on a flat plane with preservation of geodesic curvature and arc length at each sample point. In this technique arc length between sample points are approximated by chordal length. Two approaches have been considered for the development of doubly curved surfaces. In the first approach, geodesic curvature preservation is done only in one parametric direction. In this approach error concentration grows on as one moves away from the initially selected curve. This makes the technique strongly dependent on the initial curve. In the second approach, geodesic curvature preservation is done in both directions along with relaxation technique to distribute distortions in a more distributed manner.

Chapter 1

INTRODUCTION

1.1 Background

Man has been wearing shoes since the beginning of time; it is one of the basic necessity of man. Traditionally shoe designing and manufacturing have been a matter of skill and experience and even till now there has not been proper scientific methodology for designing and making it.

In modern world footwear industries are turning out to be one of the most profitable industries and competition is rising among them. People nowadays demand more; they want better quality products with large variety and choice. For economical and effective designing and manufacturing modern tools such as CAD and CAM should be utilized. Implementation of these technologies will also reduce need for skill and experience to a large extent.

A shoe, like any other product, has three aspects to it:

i. Functional
ii. Ergonomic and,
iii. Aesthetic aspect.

All the three aspects are equally important especially in the case of shoe. Functionally a shoe provides protection as well as grip to the foot. The shoe should protect the foot from harsh weather condition. It should be sufficiently hard at sole, so as to protect the base of one's feet and it should provide adequate grip and shock resistance. Comfort is a very important parameter because the shoe can be rejected even if it is functionally sound and aesthetically very attractive. The shoe should have adequate ergonomic

design with proper interior space, proper ventilation, required padding, etc. Aesthetics of a shoe is also a major factor as people like to wear shoes that add beauty and style to their lifestyle. Consumers do not mind to pay more for a shoe that appeals. A manufacturer keeps designing new styles of shoes to take care of fast changing tastes of consumers and to stay competitive in the market.

Most of the shoes these days are manufactured through mass production. The production of shoes has become analogous to the production of cars. The accuracy between the various mating components of a shoe should be with in the prescribed tolerances, so that mass production methodology can be applied. Due to increased competition and continuos demand of new styles, the industry needs to make a new model in a short time. Thus the lead-time for a new design should be small. If traditional techniques are employed each new design takes a considerable amount of time as the method is based on skill as well as on trial and error, and the product may not be competitive any longer. Thus a need exists to adopt modern technologies to reduce this lead-time and decrease development cost.

Indian Footwear industry has a tremendous export potential. India has large number of livestock that provides raw hides in abundance. The labour which is required for shoe industry is available here cheaply and in plenty. Also through the experience of centuries many persons in India have acquired adequate feel of leather, who can provide guidance as well as help in designing and manufacturing of shoes. The government of India wants to add value to products and hence it encourages industries to use leather for making leather goods like shoes, bags, etc and then exporting them.

1.2 Footwear Design Methodology

Making of shoes broadly requires three major constituents :

i. Upper of shoe
ii. The shoe last, and
iii. Sole.

A shoe last (Fig.1.1) is the solid form around which a shoe is molded. The fit of a shoe depends entirely on the design, shape and the volume of the shoe last. It is the most basic component of a shoe based on which the entire shoe design and shoe manufacturing process is carried out. The last is designed on the basis of anthropomorphic data of a foot. Each shoe last is designed for a particular heel height and toe shape. Several styles of shoes can be made on one pair of shoe lasts, but the toe shape and heel height will be the same for shoes thus prepared. If we want to have shoes with different toe shapes, it is necessary to create more than one pair of shoe lasts. A properly designed pair of shoe lasts is a solid investment and is the first step towards making a footwear that fits well. The shoe last is usually made up of wood or plastic and it has good surface finish. The upper of a shoe is designed to have the inner surface of the upper hugging the surface of the shoe last as tight as possible.

The shoe upper consists of entire upper envelope of a shoe, which gets attached to the sole as shown in Fig. 1.2a and Fig. 1.2b. The upper envelope is such that it tightly fits the corresponding shoe last. Depending upon the style of the shoe, the upper consists of a number of leather patches stitched together along with some linings and stiffeners so as to form a complete envelope. The upper can be broadly divided in to top and bottom half. The top half consists of vamp, quarter, collar, tongue and other stiffeners, whereas the bottom half consists of insole.

Fig. 1.1 Typical Shoe Last

Fig. 1.2 (a) Shoe Upper

Fig. 1.2 (b) Shoe Upper with Stroggle Stitching

Fig. 1.3 (a) Shoe Sole Top

The sole is the bottom most part of shoe (Fig. 1.3a and Fig. 1.3b). The purpose of sole is to provide protection, from dirt, water, temperature, etc. and to have shock resistance and to grip the ground. Usually the sole is made in two layers, one hard layer and other relatively soft layer. The soft layer is thick and its main purpose is to absorb shock and provide cushioning to the feet. The hard layer lies at the bottom of sole and is relatively thin; it provides grip and wears off slowly to provide long life to the sole. Design of sole depends to a large extent on the dimensions of the last. The last thus can be regarded as the basic requirement for any shoe manufacturing.

In a shoe factory various patches of the upper are cut as per the design requirements and stitched together to form the upper of the shoe. This upper is molded over the last (lasting procedure). A separate machine prepares the sole and the sole is fastened to the upper by gluing, stitching or molding. Finally delasting is done and the shoe is ready.

1.3 Surfaces and Their Development

Based on the property of developability, the surfaces can be classified in two categories, (i) developable surfaces (ii) non-developable surfaces.

A developable surface can be unfolded by a success of small rotation of the surface about the generating line or developed on to a plane without stretching or tearing. Singly curved ruled surfaces such as cone and cylinder belong to this category. As the surfaces are mathematically developable, accurate methods can be applied to develop them.

A non-developable surface is a surface, which cannot be straightened out on a flat plane without stretching or tearing. Warped ruled surfaces, doubly curved surfaces and free form surfaces belong to this category. In the case of non-developable surfaces,

the flat pattern development can be found only approximately. During the development the material will have to distort in some particular way so that a satisfactory fit can be achieved. If the 3D surface deviates from the developable property severely or if the material is relatively inelastic, an incision may have to be made in 2D pattern to remove some material (dart) or to insert an additional material (gusset). Almost all the surfaces of a shoe last are either doubly curved or free form and their exact development is not theoretically possible. However, the leather is stretchable to some extent and therefore its stretchability capability can be exploited to avoid darts and gussets. Thus some of the approximation on a development can be absorbed by leather, but the development should be such that the approximation error is the minimum possible.

1.4 Literature Review

Procedure of traditional last making is given in detail in a book by Adrian. It also provides adequate information about grading and sizing of patterns. A book for traditional pattern making by Anzelc is also a excellent reference for obtaining information about flat lasting and pattern cutting. Modern pattern cutting methods have been described to some extent in a book by Patrick.

Manual drafting techniques have been in vogue for a very long time. Consequently a appreciable amount of information is available for geometrical design using drafting procedures in books by French and Vierck(1961), Mortenson(1985) and Betterley(1978).

The differential geometry of curves and surfaces has been extensively treated in literature. Krezic(1958), Spiegel(1959) and Decarmo(1976) provide basics of differential geometry. Properties of curves and surfaces associated with mapping

differential geometry. Properties of curves and surfaces associated with mapping process have been discussed by Struik(1961) and Goetz(1970). The condition for developability for a ruled surface is mentioned by Faux and Pratt (1983) and Struik (1961).

A method for the development of a singly curved ruled surface based on preservation of arc-length and geodesic curvature has been outlined in brief by Faux and Pratt(1983) and treated in detail by Gurunathan and Dhande(1987). This method is quite accurate but can be used only for singly curved ruled developable surfaces. For doubly curved surfaces some other approach needs to be incorporated.

The method of approximating a given surface with polygonal facets and subsequent developing the surface has been the traditional approach. Shimada and Tada(1991) have assumed the surface to be elastic and elasticity is used to ensure that an approximate flat pattern development without cuts and overlaps is obtained. Parida and Mudur(1993) have also adopted the triangulation approach to obtain planar development of complex surfaces(with in acceptable tolerance) with cuts an overlaps only in specific orientation. McCartney el al.(1999) have presented algorithm based on the strain energy approach. They have measured developability condition in terms of strain energy required to deform the triangulated mesh. Thus the more undevelopable a surface is the more will be the accumulation of strain energy. Optimization procedures can be applied on triangulated data as have been done by Shewartz(1986), Cho et al.(1999). Cho has presented a method to construct an auxiliary planar domain of triangulation for tessellating trimmed parametric surface patches, which sufficiently preserves the shape of triangle when mapped into three-dimensional space. Then they approximately develop the given surface patch by minimizing the local error function for locally isometric mapping between a given and a developed surface net. Schwartz optimal flattening algorithm is quite similar to the previous approach in which they try to preserve metric structure in 3D and its corresponding flattened model.

Development can be done from a given surface in many ways nowadays. Elber(1995), Azariadis and Aspragathos(1997) have suggested a technique in which free form surfaces are approximated by sets of developable surfaces. These surfaces can then be unrolled to the plane to obtain approximate planar development with required tolerance control. The method is quite effective, but sometimes it may not be possible to approximate the surface with developables.

A class of mapping based on isometric tree has been investigated by Manning(1980) and an optimal mapping of a curved surface on to a plane has been defined with special reference to shoe manufacture. Hinds et al.(1991) have discussed pattern development for 3D surfaces based on preservation of Gaussian curvature. Bennis et al.(1991) have described a technique for piecewise surface flattening to be used for nondistorted texture mapping. This technique seems to be suitable for surfaces, which are not very complex ; also the preservation of texture makes the technique suitable for garment and shoe industry. Josef.(1998) has worked on approximation of surfaces of revolution by developable surfaces. This method could be extended to other surfaces which are generated by moving a planar curve. M Aono et al (1994) have presented a method of fitting a 2D broadcloth (deformable woolen cloth) on to a 3D curved surface so that it is everywhere in contact with the surface. Redont(1989) has proposed a technique to provide a discrete representation for developable surfaces based on the orientation of tangent plane along a geodesic. This is the simplest representation for a developable surface and yields a smooth surface while the polyhedral approximation does not do so.

Braha and Maimon (1998) has worked on creation of 3D virtual shoe last. He has suggested a technique in which set of curves are first constrained to satisfy a set of measurements given by the designer and has used the theory of design consistency to arrive at the intended solution.

1.5 Problem Statement

Shoe manufacturing and designing process is still based on skill and experience of a shoe maker to a large extent. The accuracy of quality of shoe is thus limited to the tools and technique used. In fact the traditional way is also very time consuming and is not equipped to cope with demands of fast changing dynamic society. Considerable advances have been made in CAD/CAM technologies in recent times and these modern technologies can be used for both shoe designing and its manufacturing. The designer nowadays is able to mathematically model and display an object on a graphics screen.

In present work the problem of obtaining patterns for upper of a shoe of a particular style has been dealt with. The main focus is on the problem of obtaining flat pattern development of doubly curved surfaces of a shoe last. A method for the development is suggested and applied to a particular design. Designing of particular style can be done directly on the screen once the surface definition of a last is available. The surface definition for the last is obtained by two methods. In the first method we directly scan an existing last and obtained its point data cloud. This point data cloud is further processed to obtain the surface definition. In the second method a methodology for designing a virtual 3Dshoe last has been established through which we obtain a customized shoe last in a short time.

1.6 Organization of Thesis

Many aspects of shoe designing and manufacturing have been studied and analyzed in the present work. A methodology for development of doubly curved surfaces of the shoe has been developed which could be applied to obtain patterns for a shoe last.

profitably used for Footwear applications. In Chapter 2, the basic constituents and features of a shoe are described. The process of shoe manufacturing has been described in detail. A technique to design a customized shoe last from a given point data cloud is described in Chapter 3. In Chapter 4 various existing methodologies for the development of doubly curved surfaces are studied. The method of development used in the present work is described and is applied on a shoe style. Chapter 5 concludes the thesis with technical summary and scope for future work.

Chapter 2

FOOTWEAR DESIGN-PRESENT PRACTICES

2.1 Constituents and Features Of A Shoe

A shoe, as stated earlier, consists of three main constituents, the sole, the last and the upper as shown in Fig. 2.1. All of these constituents in turn have features specific to them. These features are related to functional, ergonomic and aesthetic aspects and to the style and design of the shoe.

The bottom face of the sole is usually not made flat but has treads similar to the surface of car tyre so that it can grip the ground easily. These treads can be of various geometrical shapes like rectangular, elliptical, spiral. In molded shoe design, the sole is wrapped around on its side edges to be bonded to the upper.

The shoe last is designed based on the anthropomorphic data of the foot. Since human foot is of very complex geometry, the last is also very complex. The last contains combination of surfaces and almost all the surfaces are doubly curved or free form in nature.

A last can be described to a great extent with some critical measurements. Stick length, ball, waist and instep grith and some other measurements useful to both shoe maker and last maker (Fig. 2.2) are described below.

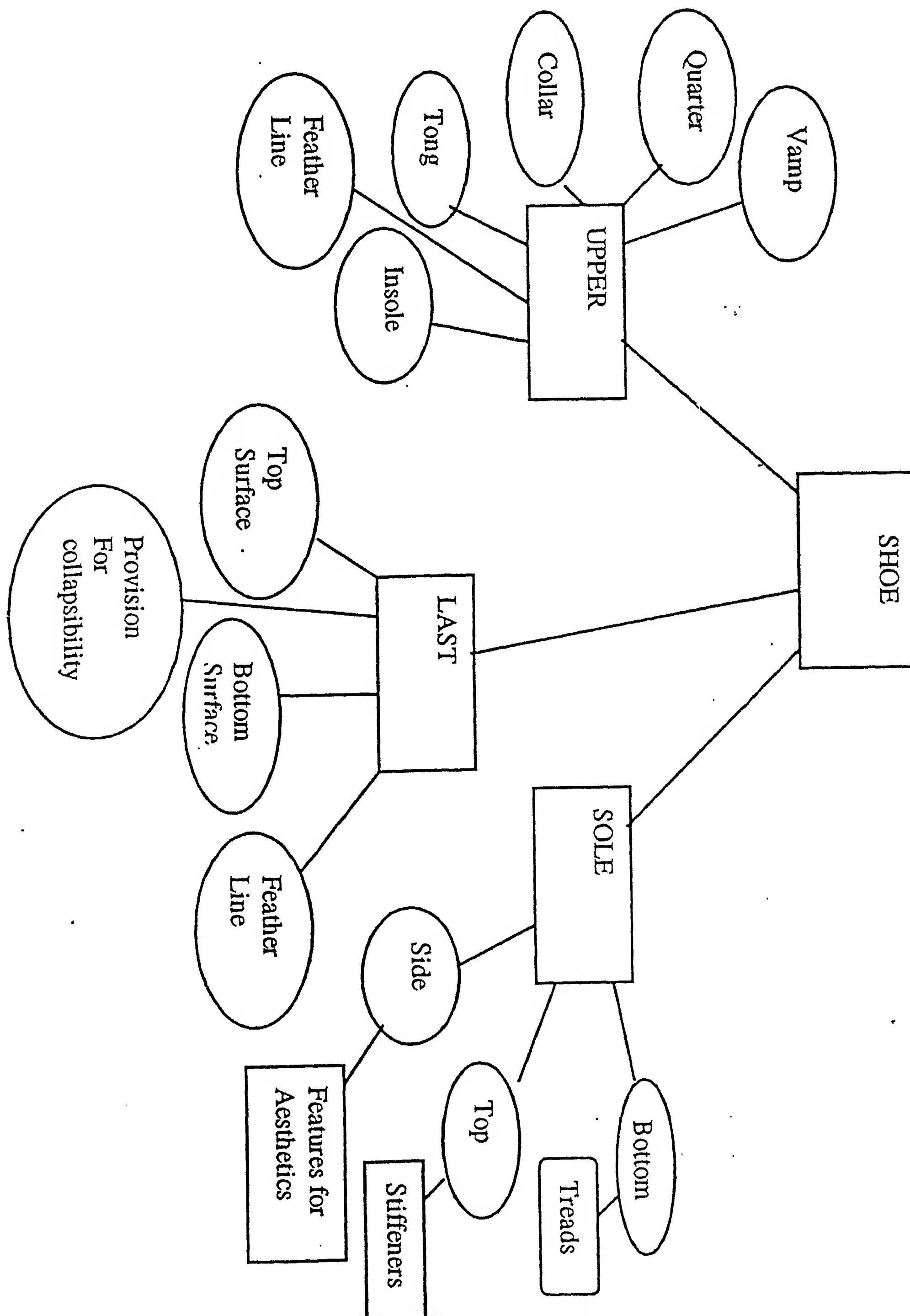
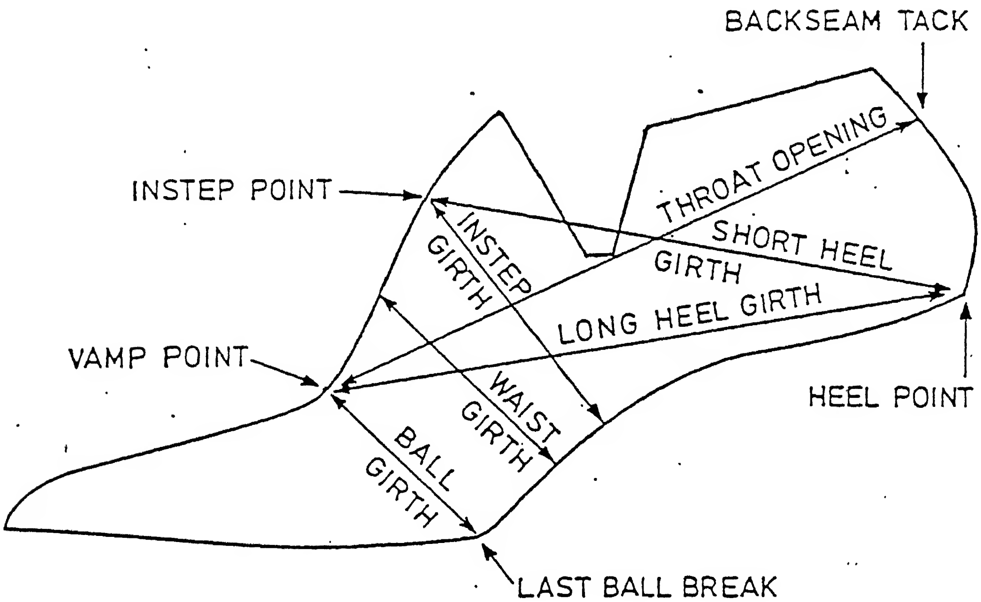


Fig 2.1 Constituents and Features of Shoe



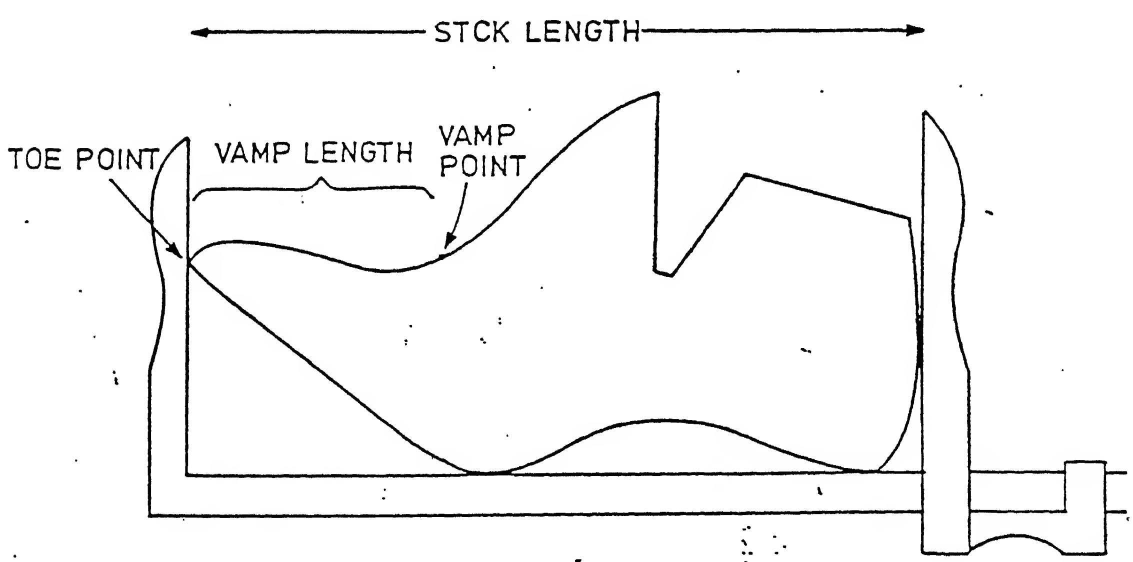


Fig 2.2 Basic Last Dimensions

Back Tack Height : The vertical distance between the heel featherline plane and the backseam tack.

Ball Girth : The greatest girth around the last, passing through the ball break. Measurement is determined by a last tape positioned to allow the tape to lay flat while tracking exactly on itself as it is wrapped continuously around the last.

Heel Point : The rearmost point of the heel featherline.

Instep Girth : The dimension around a last passing through the instep point. Measurement is determined by use of a last tape as described under " Ball Girth".

Instep Point : An arbitrary point established by the model maker for grading purposes. It is located at the approximate mid-point of the last length on the front cone profile. The instep point references the instep girth and the short heel girth.

Last Ball Break : A point located at the intersection of the shank and the forepart, tangent to a plane passing through the heel point, and perpendicular to last centerline plane.

Long Heel Girth : The dimensions around a last passing through the heel at the heel featherline and vamp points.

Short Heel Girth : The dimensions around the last passing through the instep and heel featherline point.

Stick Length : The overall length of a last as measured with a last size stick.

Throat Opening : The distance in a straight line from the vamp point to the back seam tack.

Vamp length : The distance measured along the toe profile from the vamp point to the toe point.

Vamp Point : A reference point on the top of the last forepart and at the center of the last tape as it crosses the last centerline plane, when the tape is used to measure the ball girth.

Waist Girth : The smallest dimension around a last between the ball girth and the instep girth. Measurement is determined by a last tape as described under "Ball Girth".

A provision is made to split a last in two halves. This provision is incorporated because the last and the upper are tight fitted to each other and it is not possible to insert or remove the last from the upper without collapsing the last. The last can be collapsed with the help of a small fixture, on which the last is attached. If required, a provision is also made in the design of the last for fitting it in an injection moulding machine such that an accurate alignment can be obtained.

The aesthetic look of a shoe depends to a large extent in the type and number of patterns. Different patterns are stitched together to form the upper of a shoe. It is a worth noting that on the same last shoes of many styles can be manufactured. For more number of patterns, there will be more visible stitching and the shoe looks dressy. On the other hand less number of patches give a plain look to a shoe. The types and shapes of the patterns that can be cut are limited only by creativity of the designer. But there are some critical areas where it is advisable to avoid stitching, as the stitching may be ripped of due to high stress.

The upper can be broadly divided in to two halves. The top half consists of entire portion which comes in contact with the upper surface of the last, while the bottom half consists of the insole, which comes in contact with the lower surface of the last.

The patterns, which form the top half can be classified, based on the position, which they occupy on the shoe.

1) The Vamp : It covers the front critical portion that is very important for aesthetic looks, and for comfort to the fingers. Out of all patterns this is most complex to make. Also allowances should be incorporated in the design to account for the stress points.

2) The Quarter : It lies on the side of the shoe; it is very important for comfort of feet and looks.

3) The Collar : It is at rear portion of shoe and covers the ankle.

4) The Tong : It is at the top front portion of the shoe over which the shoe laces are tied on.

Vamp lining , counter and some other stiffners are also present in the upper along with the standard constituents mentioned above. The detailed step by step procedure for the development of upper has been described in 2.4

The insole and the top half are stitched together along the featherline for completion of the upper.

2.2 Process Of Complete Shoe Manufacturing

The style and design of a shoe is selected, based on which shoe last and patterns are obtained. The patterns of the top half of upper are stitched together. The insole for the chosen last is then stitched with the top half of the upper along the featherline. This stitching (Fig. 1.2b) is of a special kind (stroggle stitching) and the accuracy between patterns should be quite high and edges of the patterns should match well for this type of

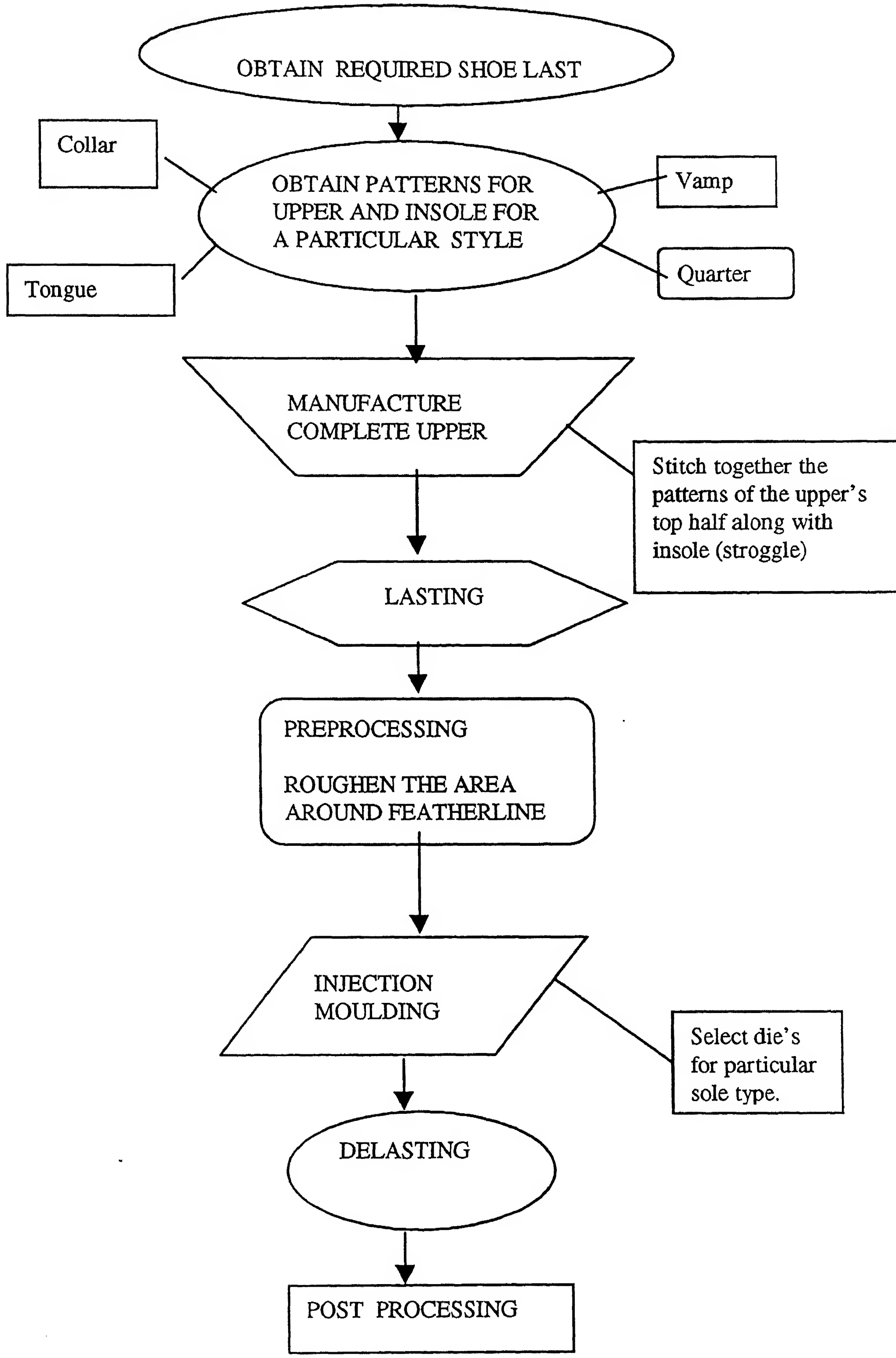


Fig. 2.3 The Flow Chart of Shoe Manufacturing Process

stitching. Once the complete upper is ready, lasting is done. Lasting is done by inserting of the last inside the upper. The last is collapsed and than is inserted into the upper.

Before the sole is moulded to the upper some preprocessing of the upper is required. The upper should be roughened through grinding around the area where the sole is bonded to the upper, so as to provide proper bonding between the two. A special kind of injection moulding machine is used to attach the upper to the sole. The machine consists of a die for casting the sole and the sole's upper is placed at the proper position. Polyurethane is injected at high pressure and temperature in to the die to form the sole.

Delasting which involves removal of the last from the shoe is done subsequently. Finally post processing involves fine finishing of the shoe. The extra protrusions which are formed during moulding are removed and also the roughened region of the upper is finished using appropriate chemicals and polishing materials. The flowchart of the entire shoe making process is shown in the Fig. 2.3.

2.3 Issues of Research

Modern technique can now be applied to shoe design and manufacturing. So far, major production and designing is done in traditional ways which are slow and not very accurate. In fact, the traditional way is not equipped to cope with the demand of the fast changing dynamic society. A shoe manufacturer should go on introducing new models in the market to stay competitive. The lead-time of the new model should be small and mass manufacturing should be economical and fast.

Some of the important processes which can be readily incorporated are :

a) Computerized Pattern Cutting : The designing can be done on the screen of the computer. Based on the design 3D surface patches can be identified. These surface patches can be developed to obtain corresponding patterns. A NC machine can then read the tool path data of these patterns from the computer and automatically cut the patterns from leather sheets.

b) Computerized Grading : By knowing certain relationship between the lasts of different sizes, a algorithm for grading can be developed. For example, if patterns for Size 7 are known, the patches of Size 9 can be easily obtained by grading through a suitable algorithm. Thus based on this algorithm we can easily obtain patterns for different sizes of last once we know the patterns for a particular last.

c) Identification of critical areas : FEM analysis of upper can be done to upper to obtain areas where maximum stretching and high stresses will occur. These areas can be modified by providing extra allowances and stiffeners.

d) Computerized stitching : The different leather patches obtained can be stitched together by computerized stitching machine. We can also set the type of stitching to be done between the different patches.

e) Die making for sole : Solid models of soles can be made and their computerized moulds could be obtained. The NC code of these moulds could be used to make new dies for the soles.

f) Production automation : Many issues which can help significantly in increasing the production rate can be automated :

1. Lasting and delasting can be done by robot.
2. Preprocessing (roughening by grinding) can be robotized.
3. Proper fitting of shoe uppers to injection machine can be automated.

4. The mixing of polyurethane in required composition can be done by an automated stirrer.

2.4 Process Of Complete Upper Manufacturing

A step by step procedure to manufacture a upper of a shoe through traditional method is described in this section. The process described is for a particular style of shoe and only the patterns for that style are used in the following procedure.

1 Getting patterns

The patterns and linings for the particular shoe style are first collected together. Vamp, Quarter (inside), Quarter (outside), Tong, Pad lining, Vamp lining, Leather board Counter, Pad foam, Toe Cap foam are the patterns of the upper of this shoe and are shown in Figs. 2.4-2.6. All the patterns have notches made in them, which are provided for easy and accurate alignments during the manufacturing process

2 Edge Painting

Edge painting is done on the edges of the patterns which are to be stitched together (Fig. 2.7). Usually the side edges of the leather patterns are of some different colour than that of the visible outer colour of leather pattern. This may spoil the looks of the shoe because the side edges will be visible even after stitching. To avoid this difficulty edge painting is done before stitching of patterns is done.

3 Skiving procedure

Skiving involves thinning out the thickness of the leather by grinding or roughening.

Skiving is done on the edges of the two patterns which are to be stitched together (Figs.2.8-2.9). During the stitching of two patterns the edges which come together usually overlap each other and if skiving is not done on these overlapping edges the resultant overlapped area will be very thick. It would be then difficult to stitch this area and also the looks and design of the shoe would then get spoiled.

4 Pad Making

As shown in Fig. 2.10 the pad foam is positioned properly in side the pad lining. The pad foam is then bonded to the pad lining. The pad lining is folded in a such a way that notch to notch are aligned. Pad decoration stitching is done subsequently (Fig. 2.11). This stitching is basically to provide aesthetic looks and can be done based on the style required.

5 Preparation of Vamp assembly

Sticking of Toe cap foam on vamp lining is shown in (Fig . 2.12) . The sticking of vamp with vamp lining is shown in (Fig. 2.13). The edge to edge alignment between the two is very crucial and should be performed accurately.

6 Preparation of Quarter assembly

Inside and outside quarters are stitched together as shown in (Fig.2.14). The proper alignment can be obtained with the help of notches. Leather counter, which provides added stiffness to the quarter is then glued inside the quarter as shown in (Fig. 2.15) with proper alignment.

7 Stitching together the Pad and Quarter assemblies

The pad assembly and the quarter assembly prepared till now are positioned properly and stitched together as can be seen in(Fig. 2.16).

8 Vamping

Vamping involves the stitching of vamp assembly to to the rear half of the shoe along the edges (Fig. 2.17). The edges to be stitched are already edge painted and skived as mentioned before. The proper alignment can be obtained with the help of notches.

9 Tong Positioning

Finally the tong is placed and stitched on the vamp edge with proper alignment as can be seen in Fig. 2.18.

2.5 Traditional Method of Obtaining Patterns of a Shoe from the Flat-Pattern Development of the Last

In the traditional way the standard patterns are obtained through the existing flat-pattern development of the shoe last. The development is spread on a flat sheet and then marking is done on it for different patterns as can be seen in Fig. 2.19 and Fig. 2.20. The flat pattern is then cut along these marks to obtain the standard patterns. The method has limitations because a designer is not able to visualize clearly how the patterns will come up when they are actually placed over the curved surface.

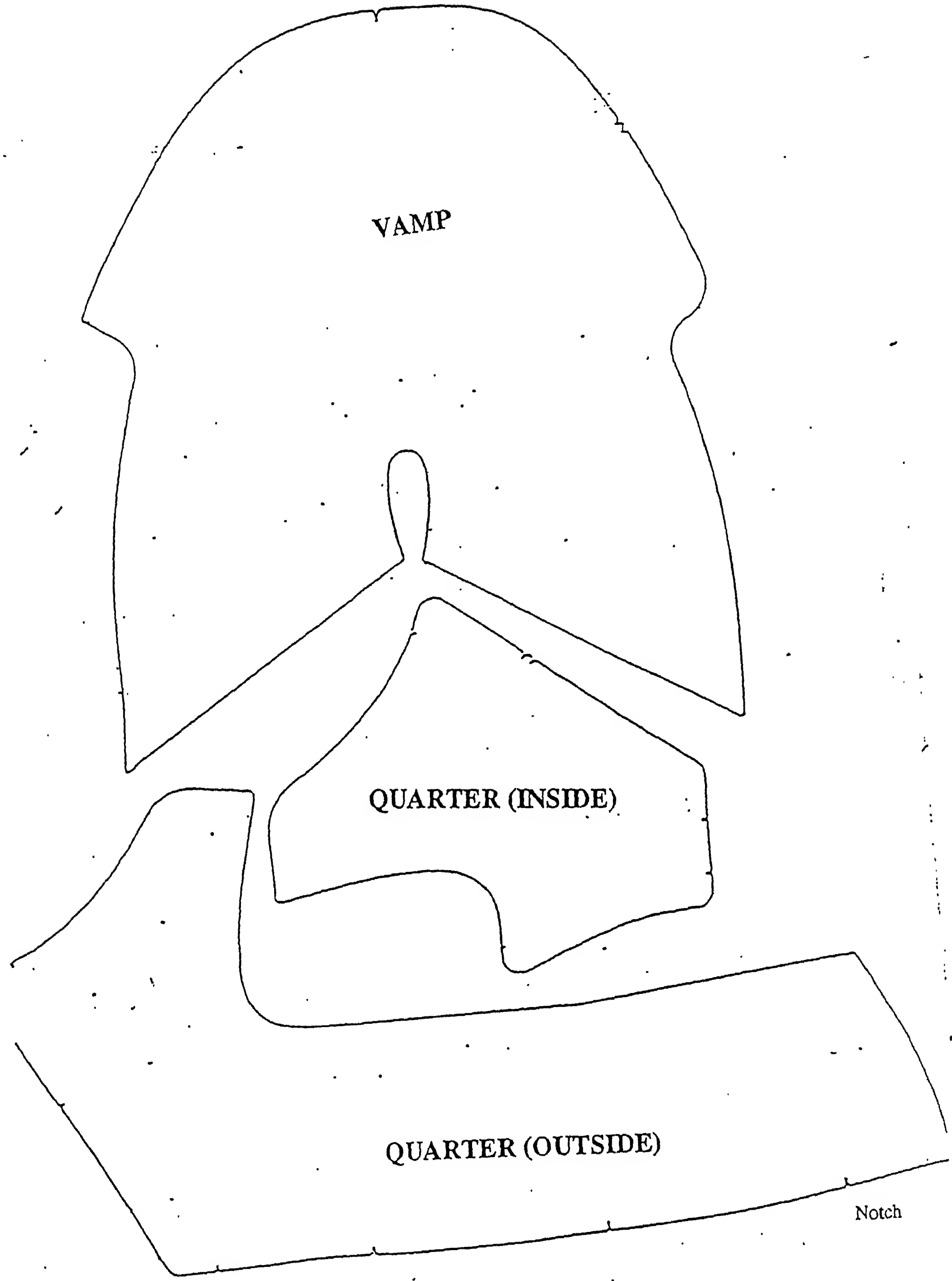


Fig. 2.4 Basic Patterns

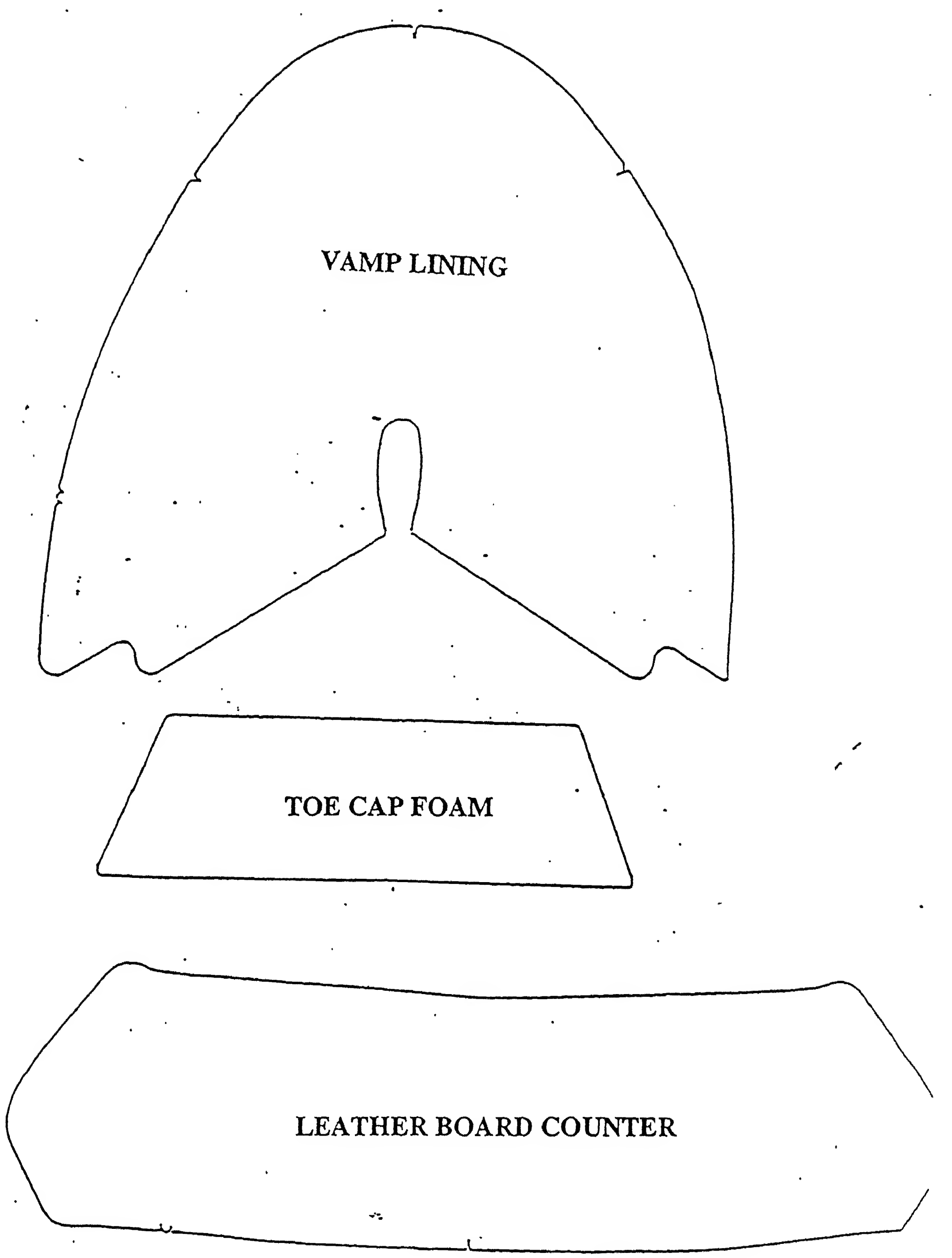


Fig. 2.5 Basic Patterns

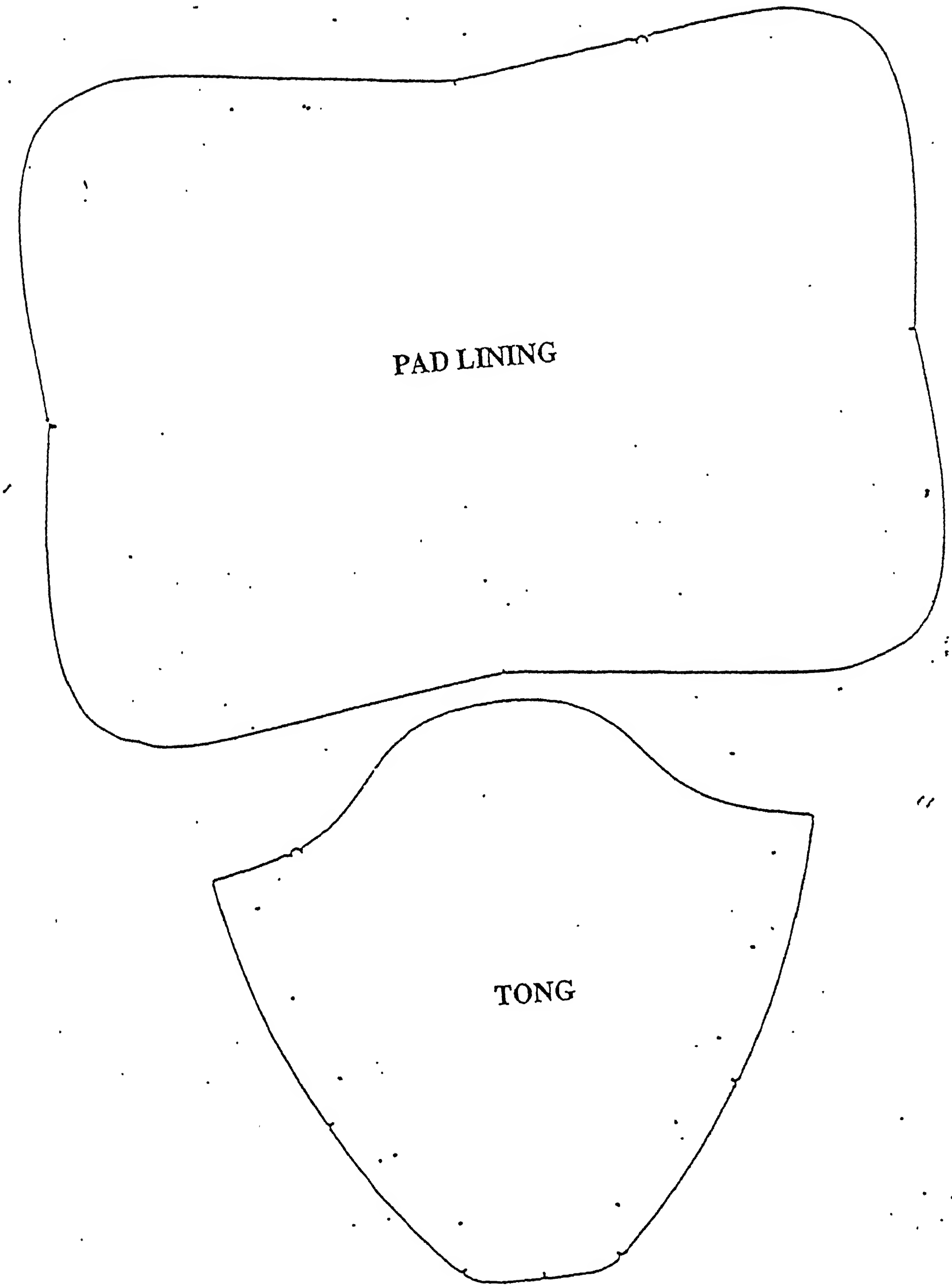


Fig. 2.6 Basic Patterns

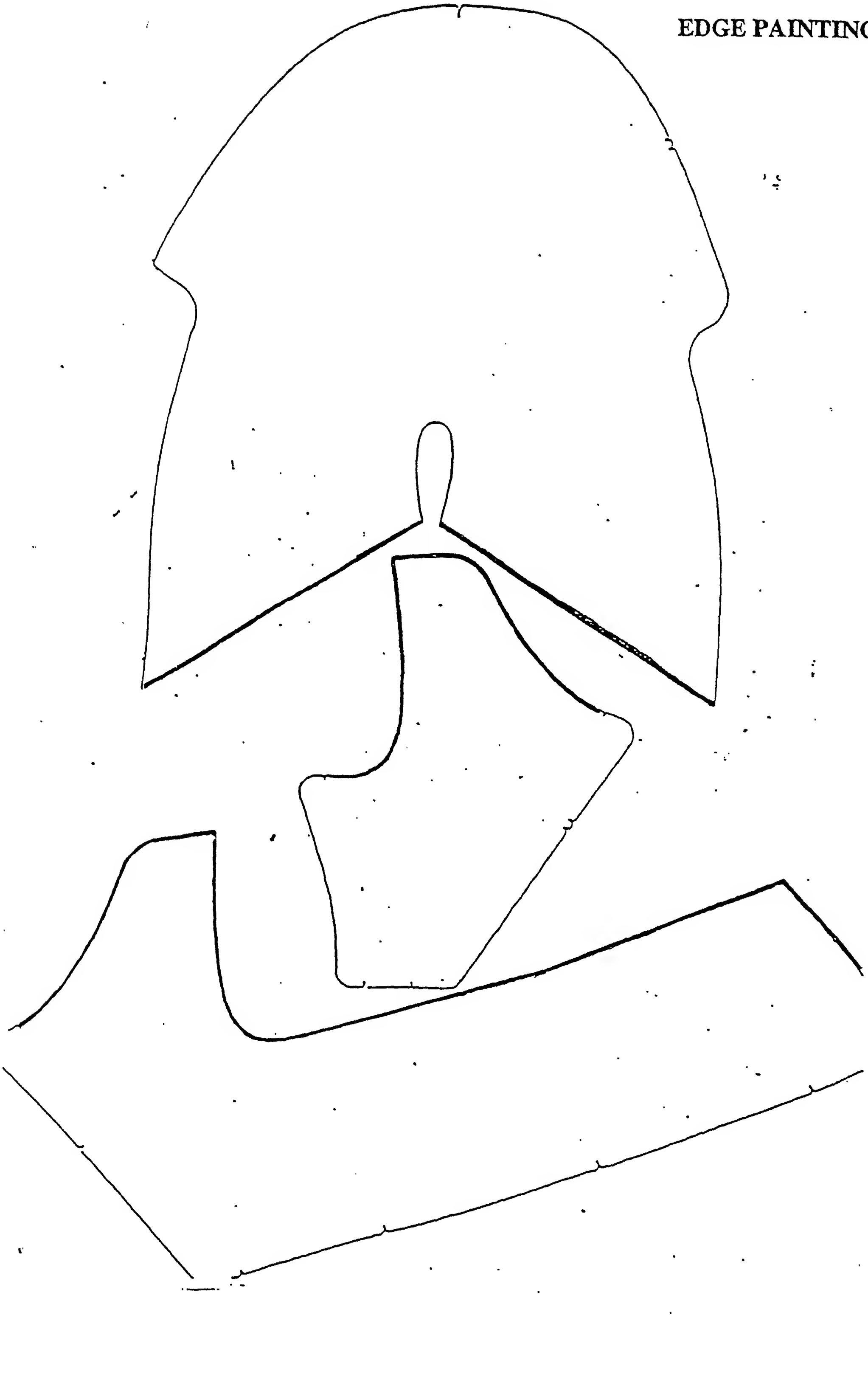


Fig. 2.7 Edge Painting

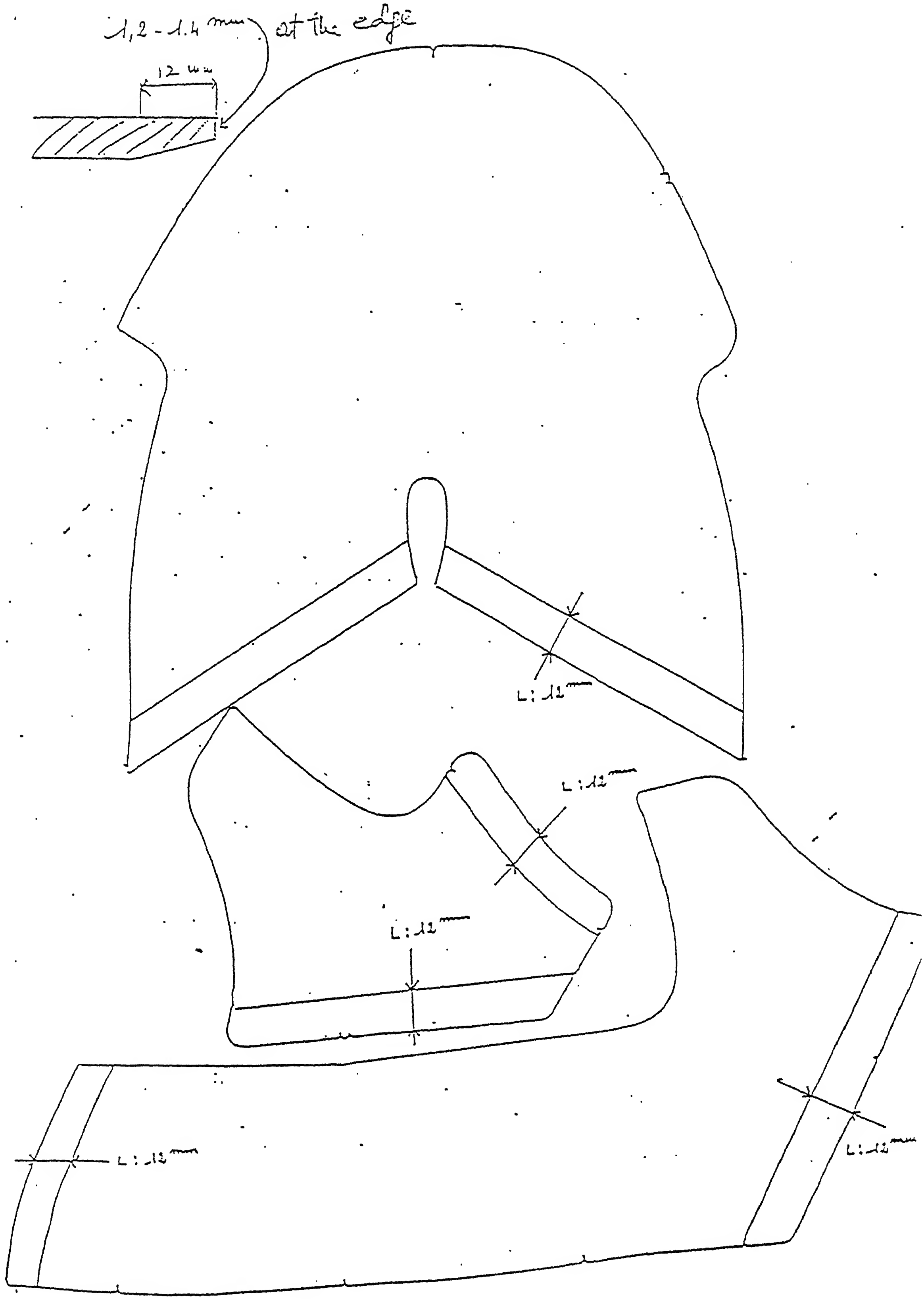


Fig 2.8 : Skiving Procedure

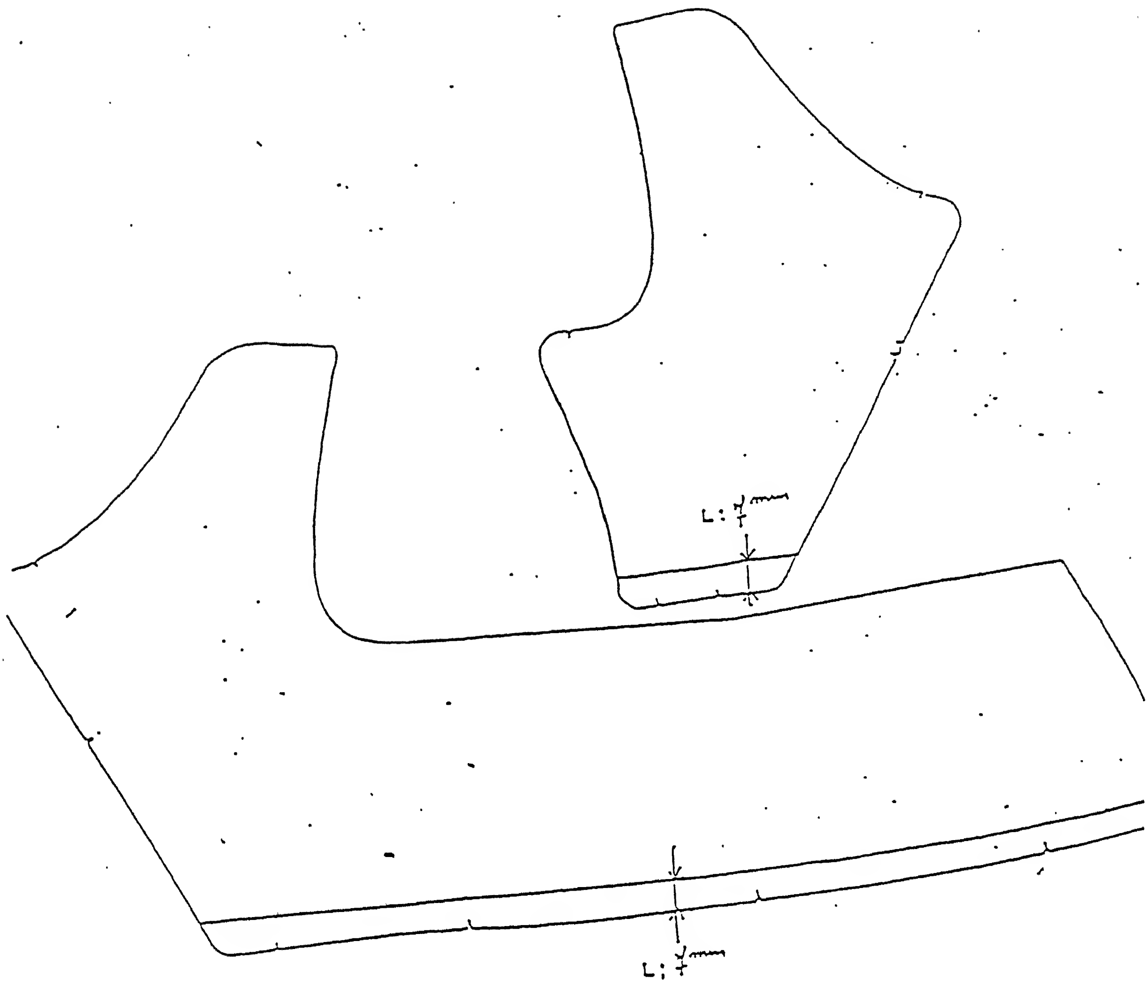


Fig 2.9 Skiving on Grain Side

PAD MAKING

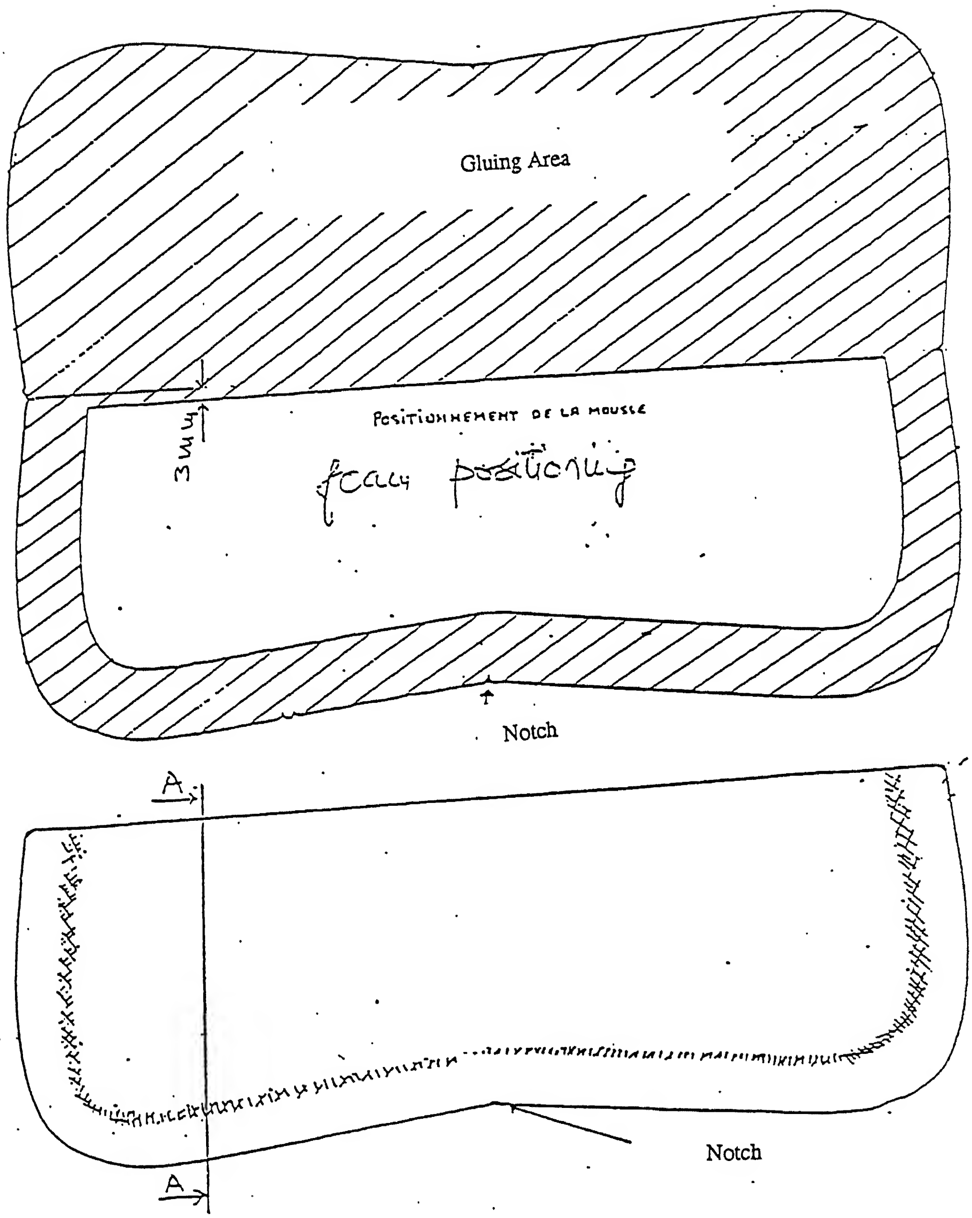


Fig 2.10 Pad Making Procedure

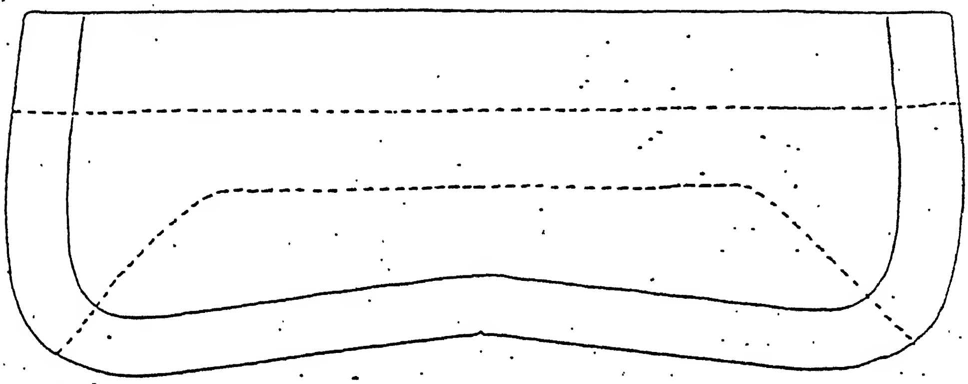


Fig. 2.11 Pad Decoration Stitch

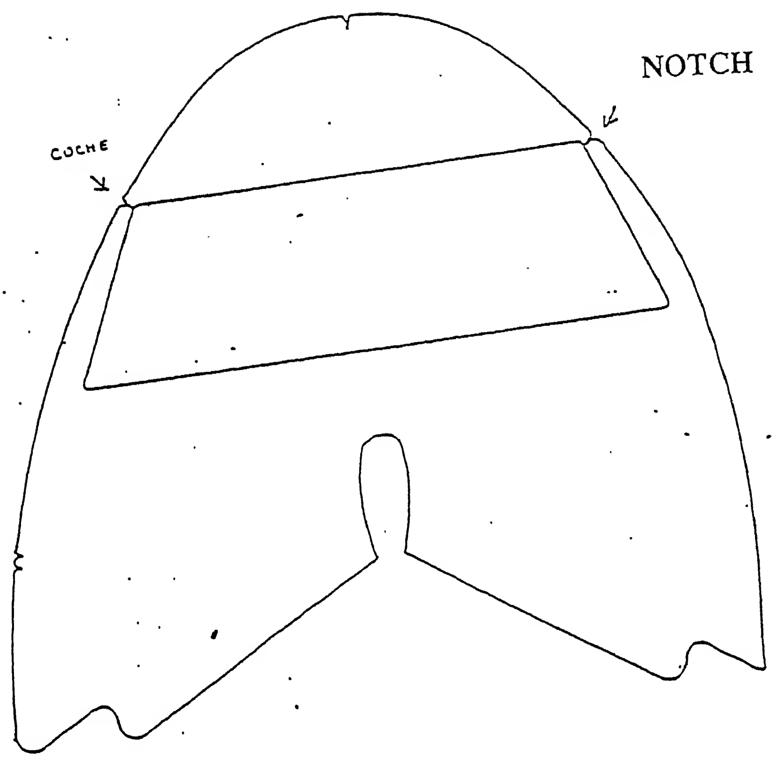
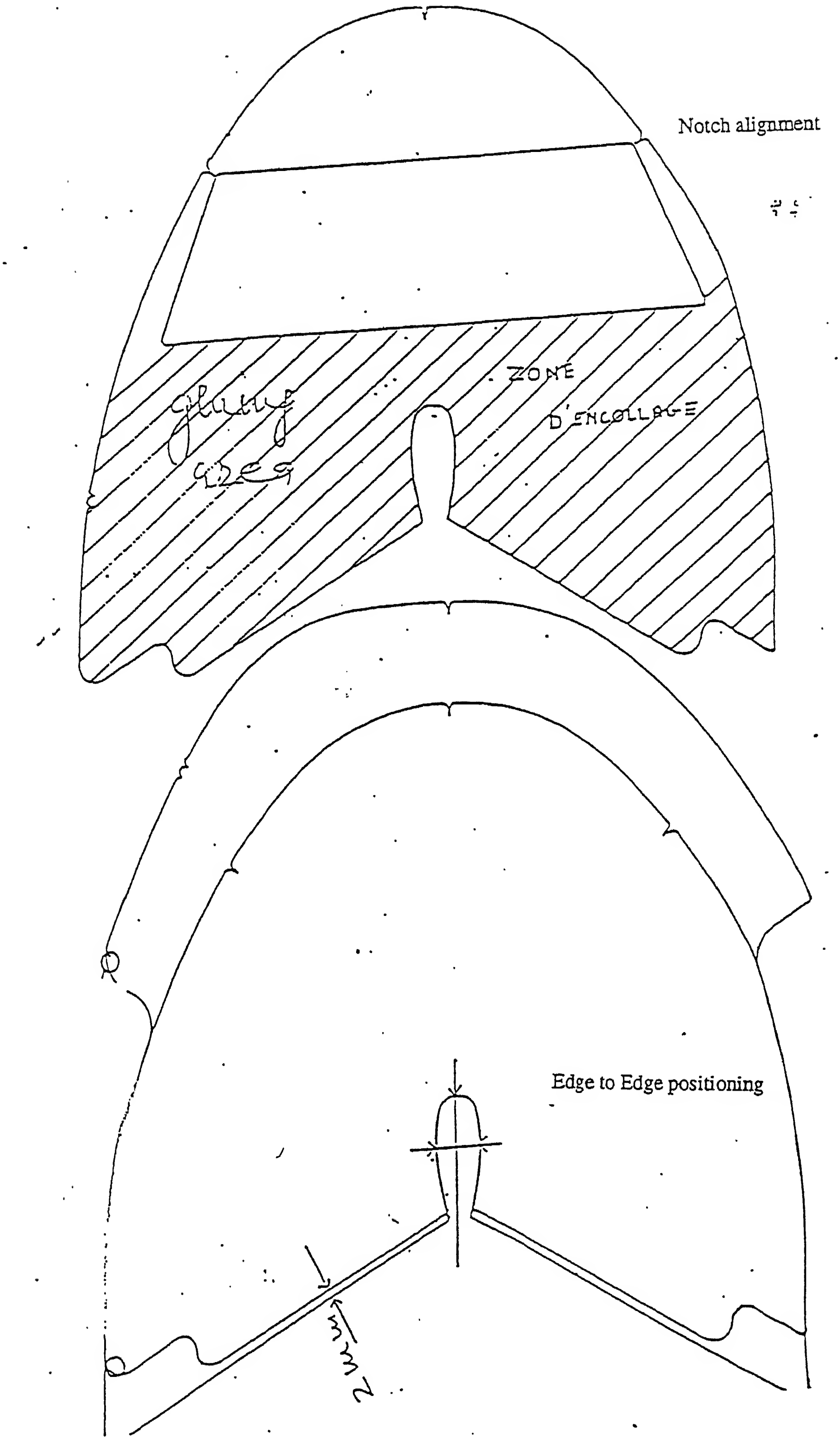


Fig. 2.12 Toe Cap Foam Stitching



Rounded side contains thumb.

Fig. 2.13 Vamp Prepration

INSIDE AND OUTSIDE QUARTER STITCHING

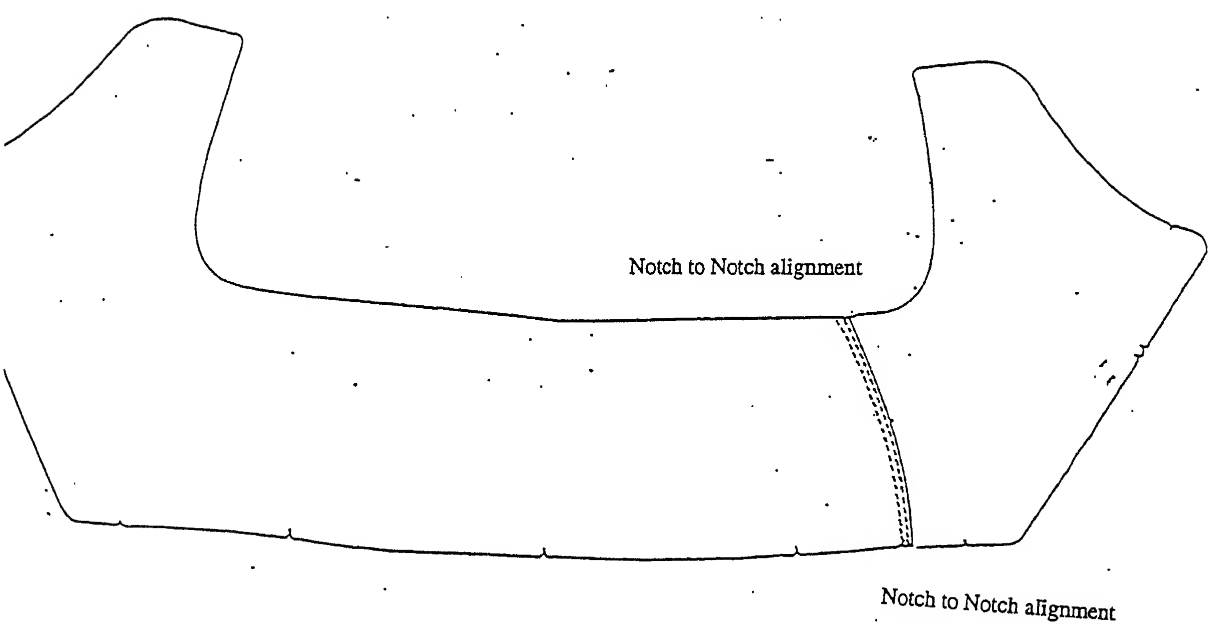


Fig. 2.14 Inside and Outside Quarter Stitching

LEATHER COUNTER GLUING AND POSITIONING

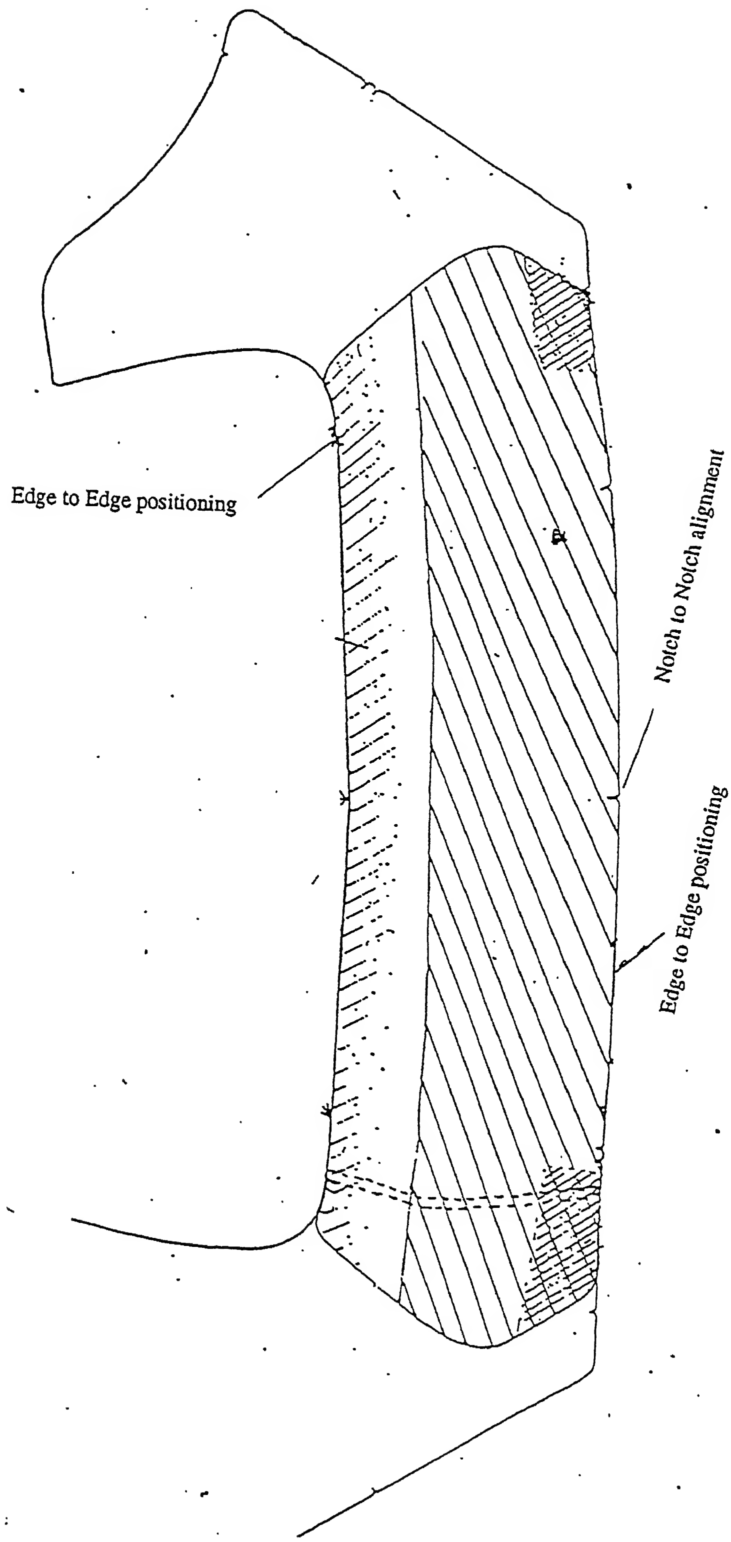


Fig 2.15

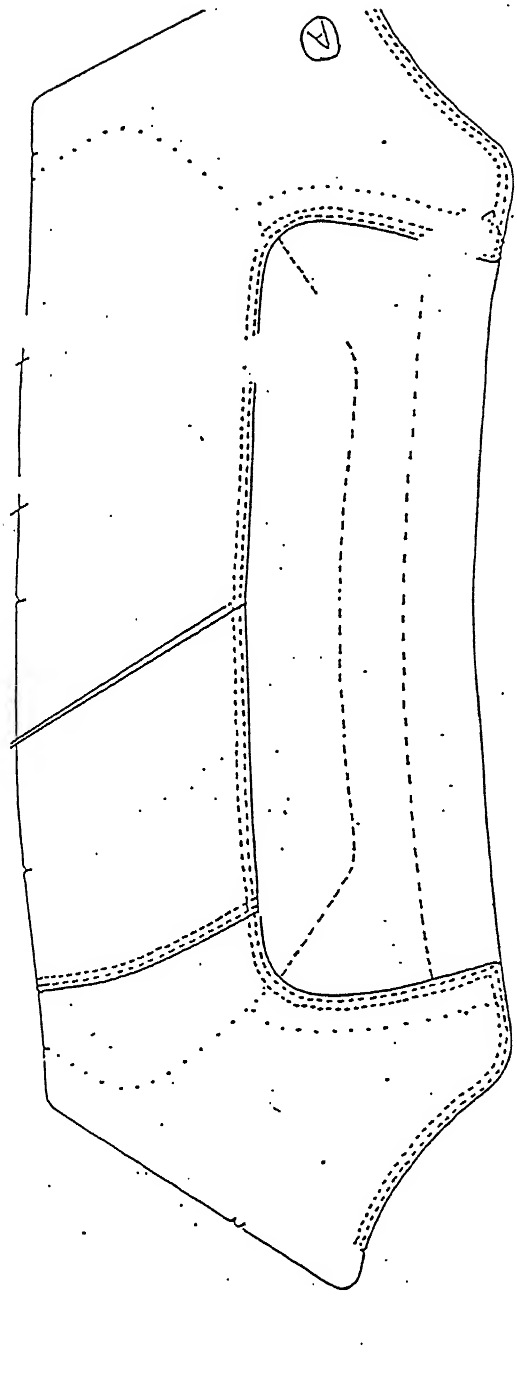


Fig. 2.16 Pad Positioning

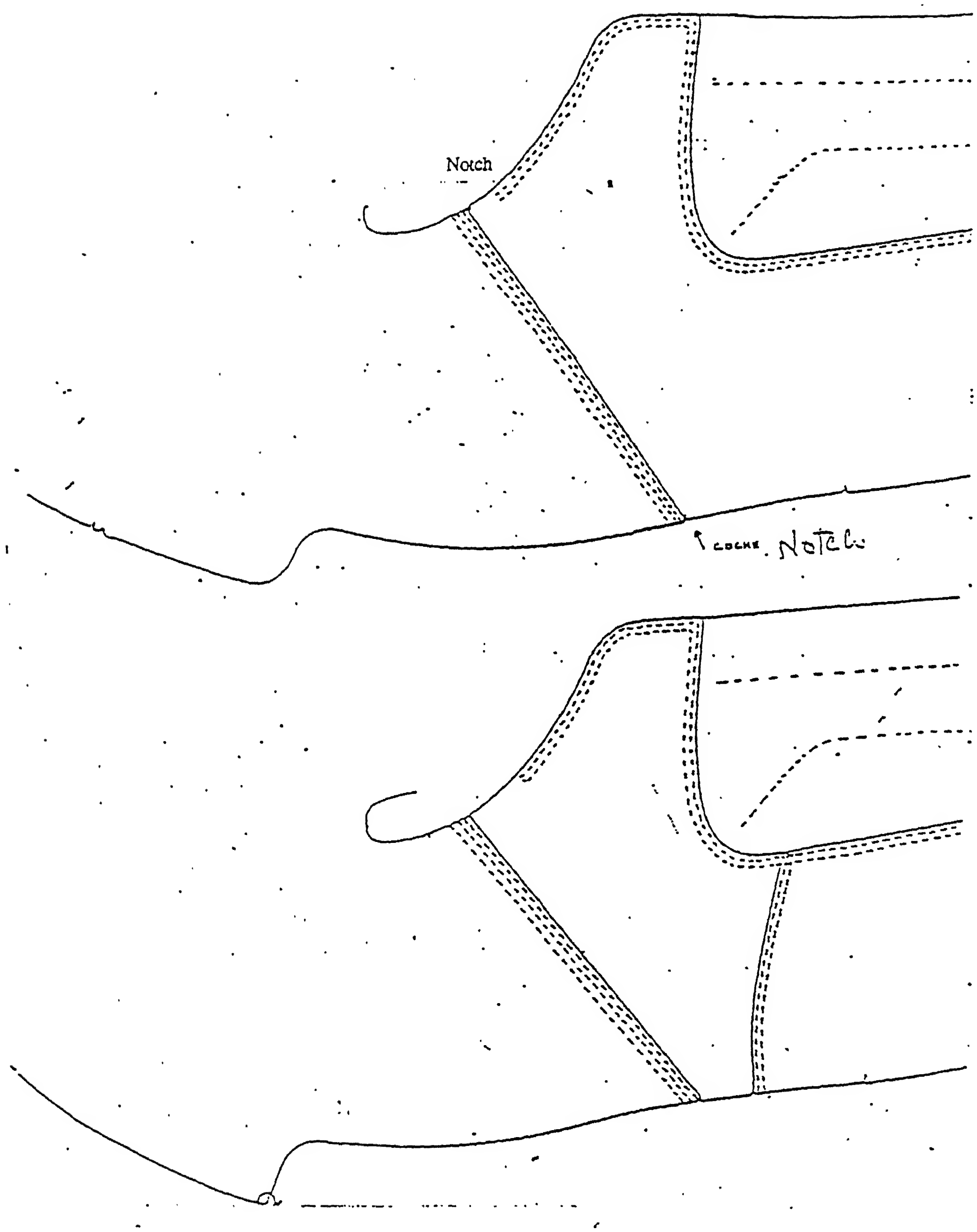


Fig. 2.17 Vamping

TONG POSITIONING

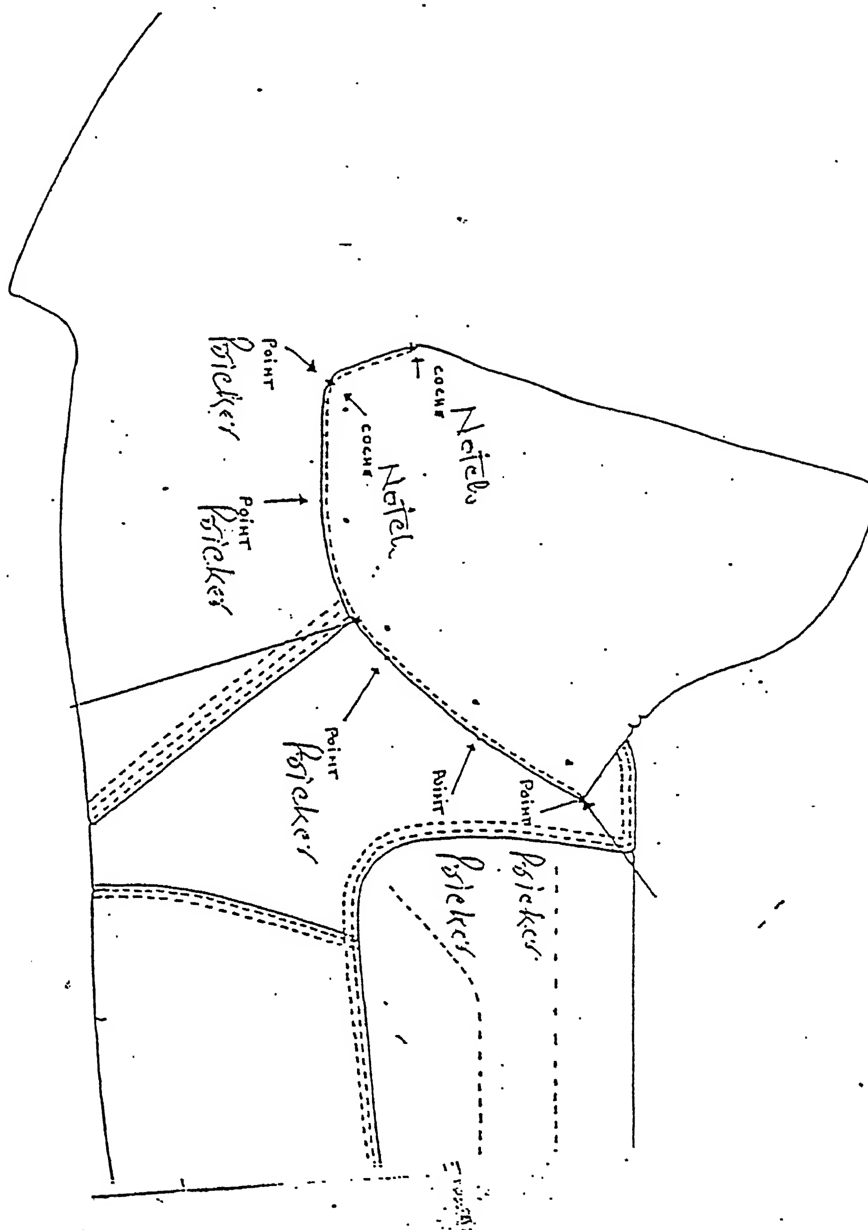


Fig 2.18

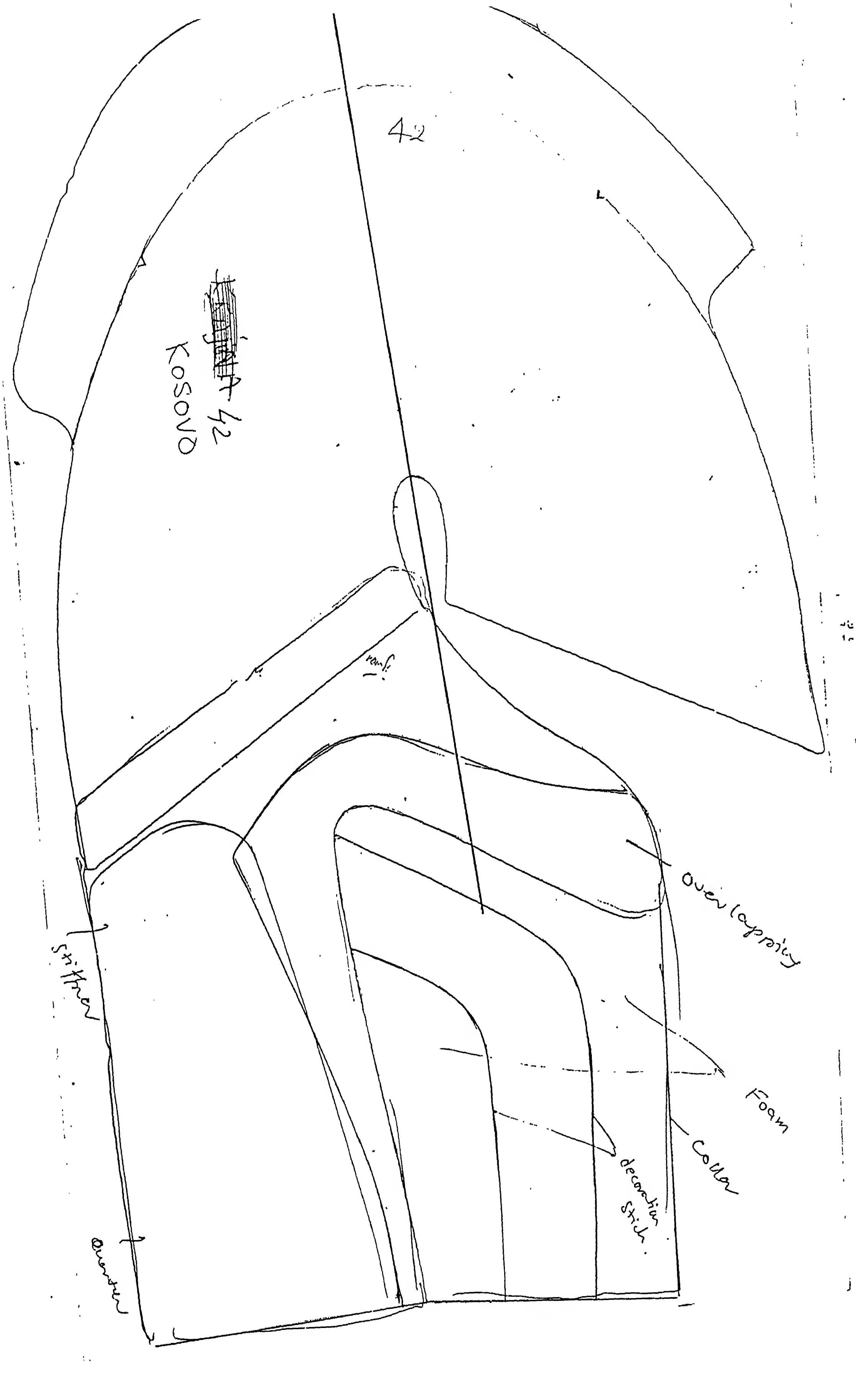


Fig. 2.19 Traditional Shoe Designing

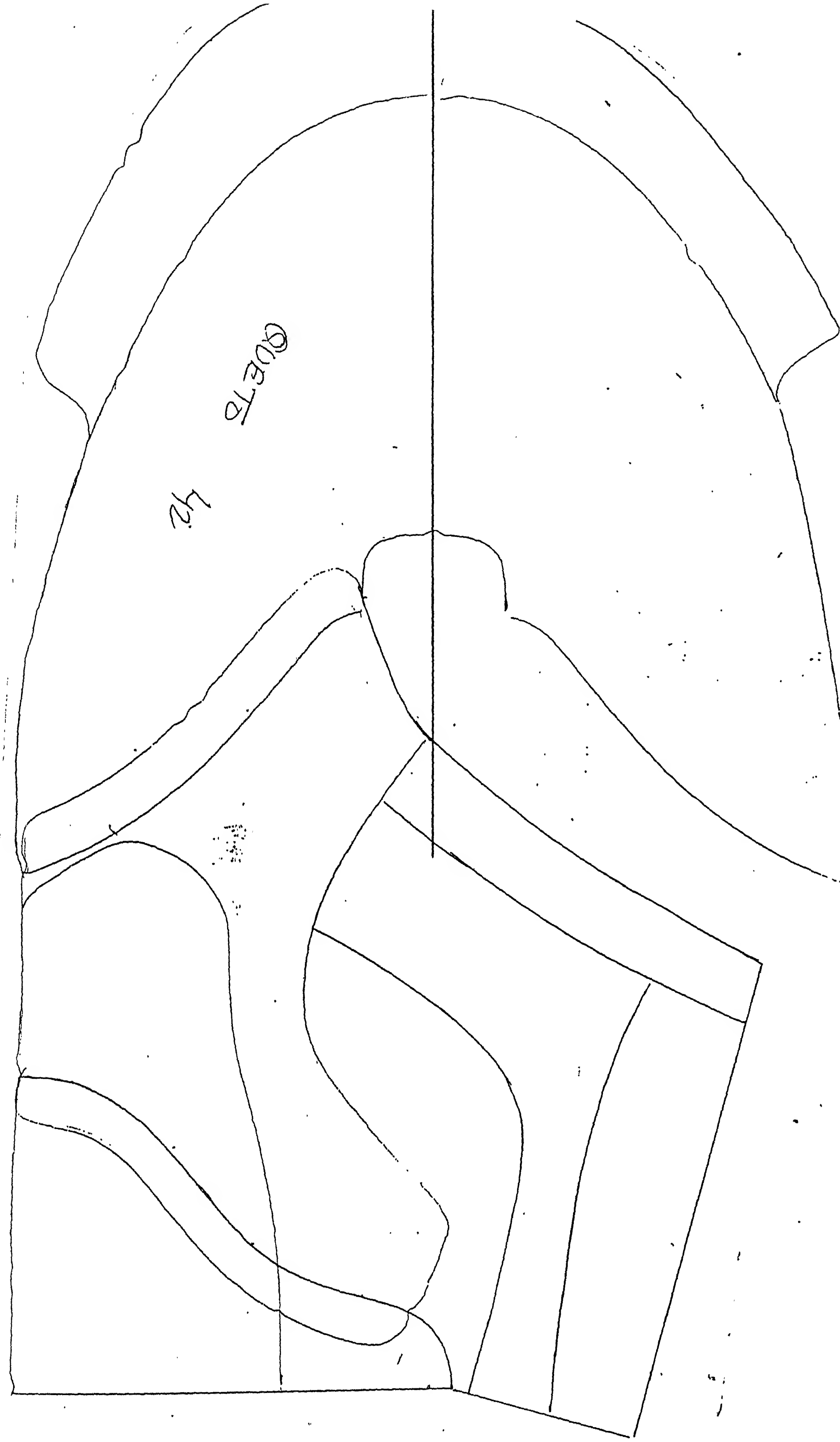


Fig. 2.20 Traditional Shoe Designing

Chapter 3

DESIGN OF SHOE LAST USING POINT DATA CLOUD

3.1 INTRODUCTION

Previous to 1900's before the mass production concept had started, everyone had their shoes made by the local shoemaker, on their own personalized shoe lasts. Nowadays the scenario has changed a lot, mass production has standardized every thing including the size of the last. Although the lasts are designed and made after a lot of survey and research of foot, the lasts are still available in standardized stepped variations. A person may be very luck if his foot matches perfectly with the standardized dimensions of the last of the shoe he usually wears. A person with abnormal foot will not be able to get a shoe in the market. Thus a need for customized shoe exists. A customized shoe fits properly, it gives a nice and more comfortable feel, and also the whole body support gets properly distributed with it. In this chapter a approach for creating virtual 3D last is demonstrated. The patterns for these virtual lasts so generated can be obtained by the method of flat-pattern development explained in chapter 4.

There are two methods by which customized shoe last can be designed and made. In the first method the foot, for which customization has to be done, is first scanned through a optical or touch scanner and the point data cloud of the foot is obtained. A search is made for a standard existing shoe last which closely approximates the given foot and the point data cloud of this last is also recorded. The two point data cloud are then registered with each other with the help of some common reference points. After the registration the areas of intersection of the two point data clouds are investigated and the critical zones of foot are checked properly. Wherever changes are required,

existing last which is almost to the size of the foot. Also in this approach we need to scan the complete foot and obtain its point data cloud which can be costly and time taking. The process also needs sophisticated software for registration of the point data clouds.

The second method which is proposed is comparatively very fast and user interactive. In this model complete foot is not scanned but only some of the critical dimensions of the foot are scanned. Based on these critical points a set of curves with required constraints are constructed. Once these curves are created, surface patches based on the curves can be created subsequently. Shape and slopes of the curves can be changed either by variation of control points or by variation of tangent factors as the case may be based on the type of formulation done. The curves and surface patches should have the required continuity among themselves. The present methodology is used for obtaining a lasts surface definition and is described below.

3.2 Point Cloud Analysis

In point cloud analysis identification of certain key points based on the critical measurements of a last are first identified. A procedure to scan and analyze the data obtained is described below.

Foot of a person is kept on a flat plane (x,y) and with the help of a marker entire contour which covers the outer boundary of the shoe is sketched. Based on the heel requirement certain key points such as heel points height z is recorded. In a shoe last, once the heel height is known, the toe spring (Fig. 1.2) and ball break point can be obtained by set of certain existing formulas. The position of certain other critical points such as vamp point and instep point can then be obtained by measuring the approximate ball girth of the shoe, long heel girth and short heel girth of the foot approximately.

1. The outer profile marked by the marker is scanned by the scanner and all the points lying on it are recorded. Perform the following steps subsequently to obtain the coordinate system for the entire last design.

1) Find the minimum y coordinate y_{min}, out of the given points .
2) Translate the current coordinate system to the lowest point y_{min} of the 2D profile.
3) Rotate the coordinate system about z axis in an incremental manner.
4) For every orientation find out Δy at every incremental rotation.
5) Select the angle θ_f,.for which Δy is maximum.
6) Set up final coordinate system rotated at θ_f with the current coordinate system.

2. Once the coordinate system is fixed we can identify the constraint points which are critical for featherline definition are identified. The points along with the standard terminology are shown in Fig. 3.1

3. The heel height is given to this 2D profile by giving the required z height to the lowest point of feather line. The point which we now obtain is the heel point R_5. Other points R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9. Can be then given elevation based on the height of heel point. The height of all these points are related to major length and heel height by certain standard formula's (Adrian 1991). Generally the more the heel height will be less the toe spring will be.

4. Identify the approximate position of the toe point. This can be done by measuring the ball girth of the foot.

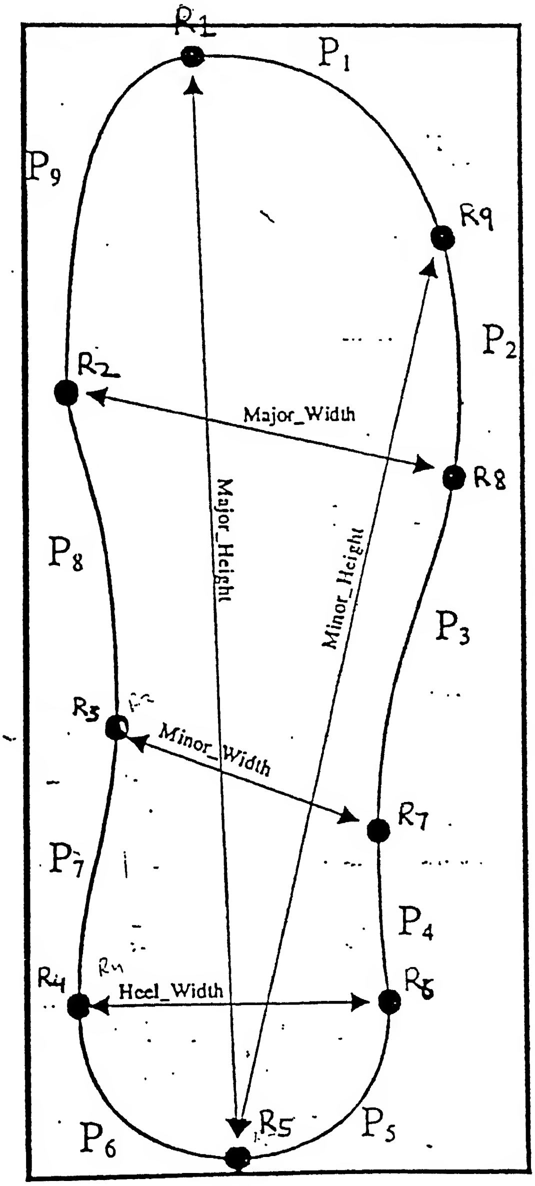


Fig. 3.1 Basic Dimensions of Insole

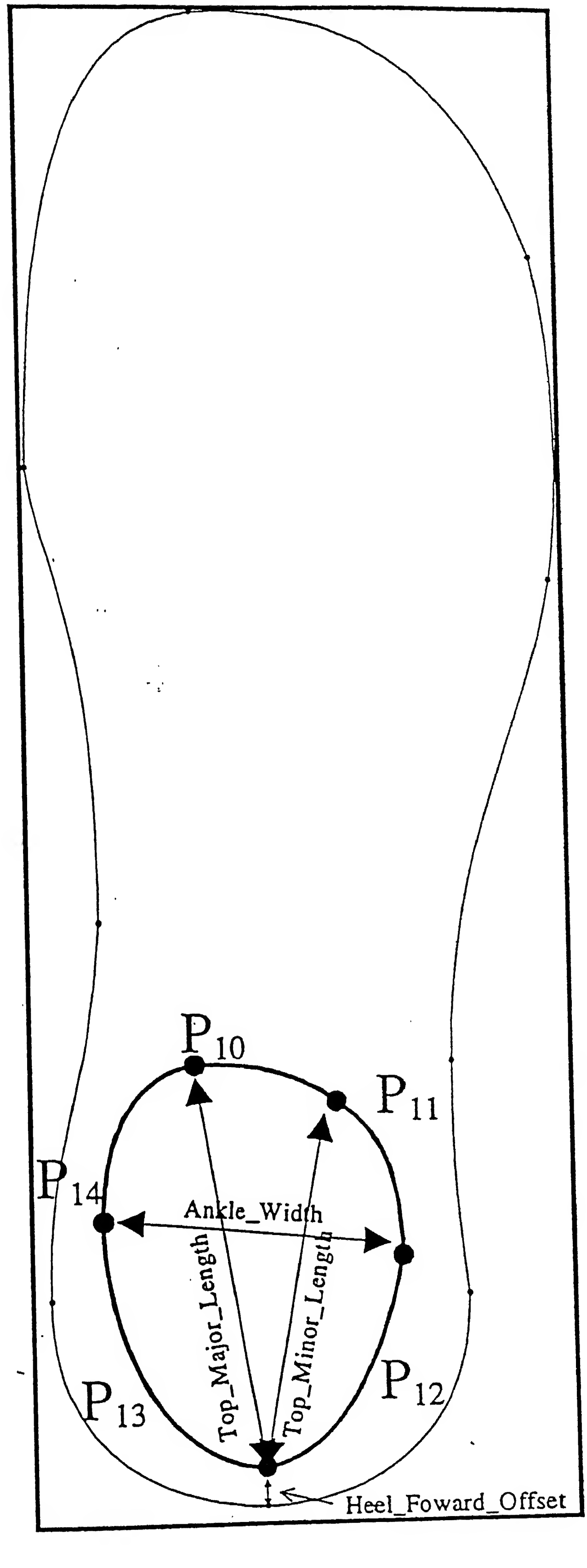


Fig. 3.3: Basic Dimensions of Outer Heel Cup

5. Instep point and backseam Tack point can be also be located at their relative position by measurement of foot dimensions.

6. Depending upon the height of the shoe, a profile is scanned close to ankle as shown in Fig.3.2. The critical control points are also identified on this profile. Low ankle shoes do not reach up to the ankle and hence there is no need to take such a complex profile, instead we can take upper curve to be flat and much longer.

7. Identify some points along the center of the last and almost in plane with the vamp point and backseam tack point as shown in Fig. 3.3. These points will form the middle curve for later use.

8 Some more points are identified which are selected so that they can be used for surface patch fitting. The points g_1, g_2, g_3, g_{1b}, g_{2b}, g_{3b}, g_4, g_{5b} are the points obtained at constant value of x coordinate. The points g_1, g_2, g_3, g_5 are on the visible side where as g_{1b}, g_{2b}, g_{3b}, g_{5b},etc, are points on the other side as shown in Fig. 3.4

3.3 Sailent Curve Design

Once the position of all the critical points in space relative to our coordinate system have been obtained ,curve fitting is done through these points.The curve fitting is done piecewise and the individual curves should satisfy the required constraints of tangency and position. Any type of curves (Bspline, bezier or Cubic) can be fitted between the points but normalized cubic spline curves have been used here for simplicity. Provision is also made on the curves so that their tangency factor can be manipulated by the designer because the shape of a cubic curve is dependent to a large extent on the

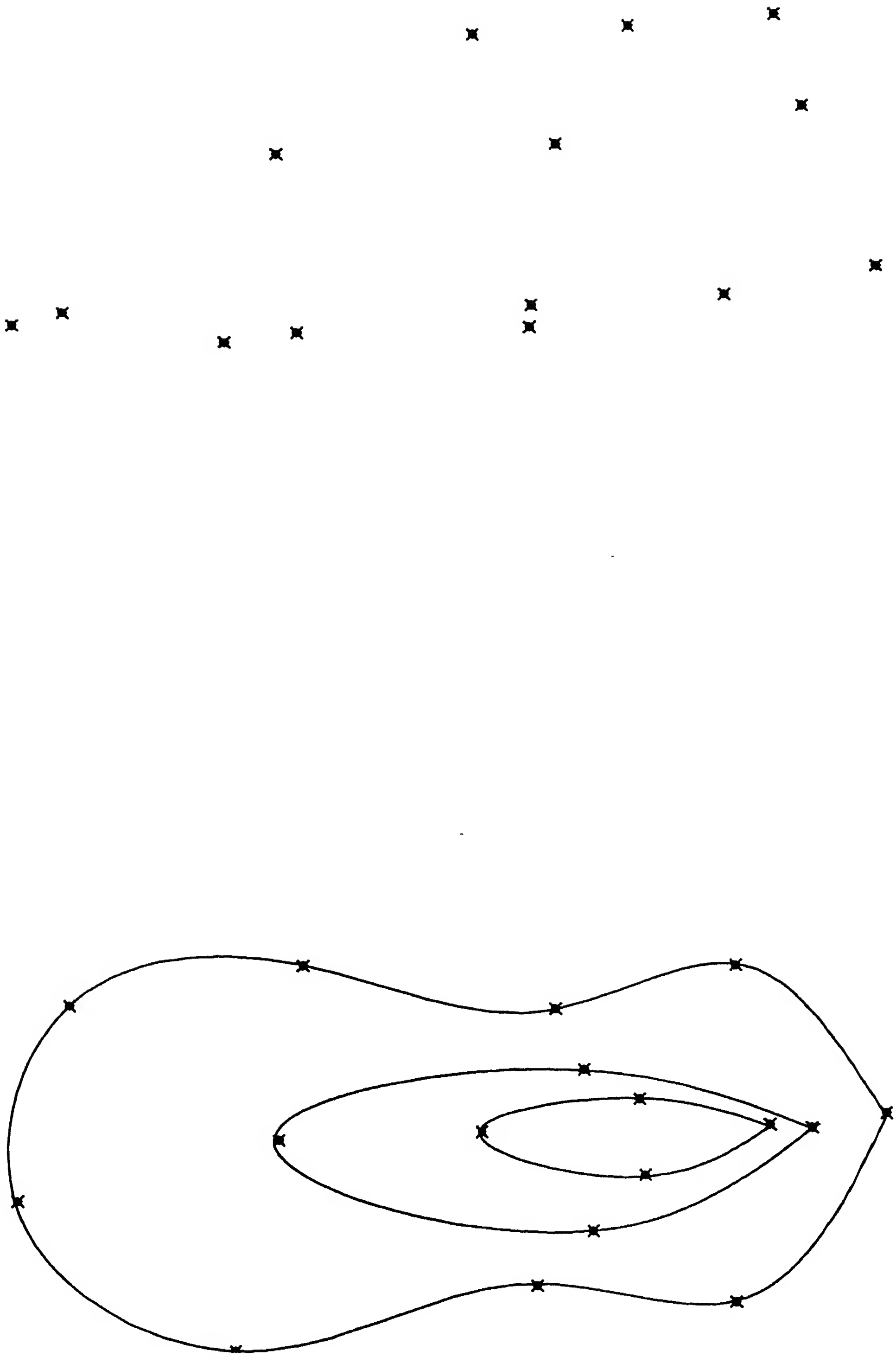


Fig. 3.3 Critical Points Of Shoe Last

magnitude of tangent vectors at the end points. A step by step procedure of curve designing is given below.

1. Points of the feather line (lower outer curve) are joined with cubic curves as is shown in Fig. 3.5. The curve segments are such that they maintain position and tangent continuity at their intersection point.The shape of the segments can be varied by changing magnitude of tangent vector.

2. The points of the middle curve are joined piecewise through cubic curves. These curves also maintain tangent continuity at the intersection point and can be manipulated by the user through changes in tangent factors.

3. The outer upper curve is fitted with piecewise cubic curves as done in the other two profiles.

4. The featherline curve(lower outer curve), the middle curve and the outer upper curve are now reparametrized. The normalized cubic splines are parametrized based on the points of constant x g_1, g_{1b}, g_2, g_{2b}, etc. The curve segments formed C_1, C_2, C_3, etc are shown in Fig. 3.5.

5. Once the three curve profiles are obtained points of constant x (g_1, g_2, g_3) are joined together to each other maintaining the tangent continuity as shown in Fig. 3.5. Also a curve is joined between vamp point and point g_5 with required shape control facility.

6. A curve between vamp point and major length point g_6 is constructed and also curves between vamp point and points g_5 and g_{5b} are formulated such that they have the required tangent continuity at vamp point.

7. For the base of the last curves are created which join g_3, g_{3b} and g_5, g_{5b} as shown in Fig. 3.5. The shape of these curves should be manipulated by designer to obtain required shape of the base of last.

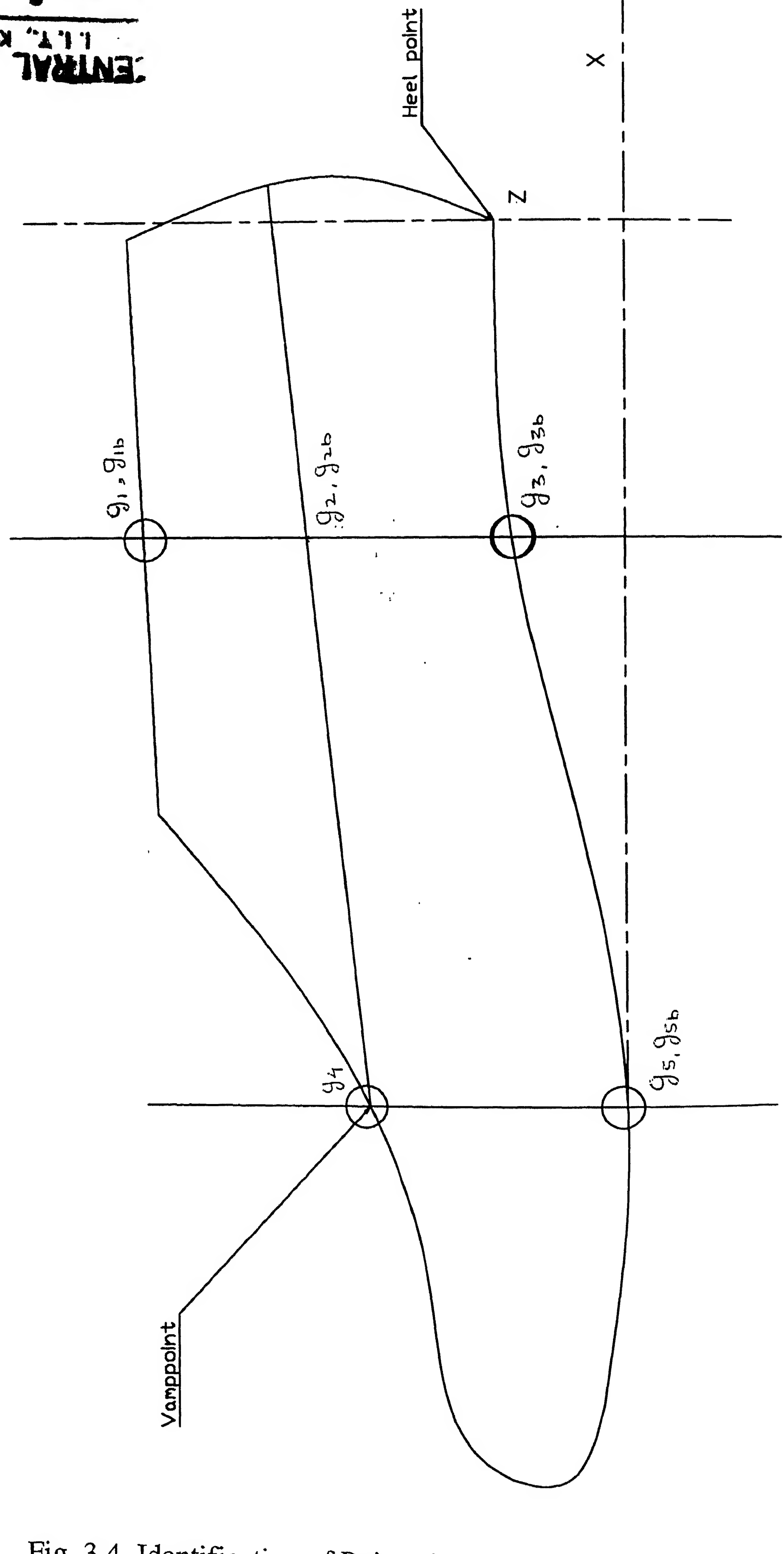
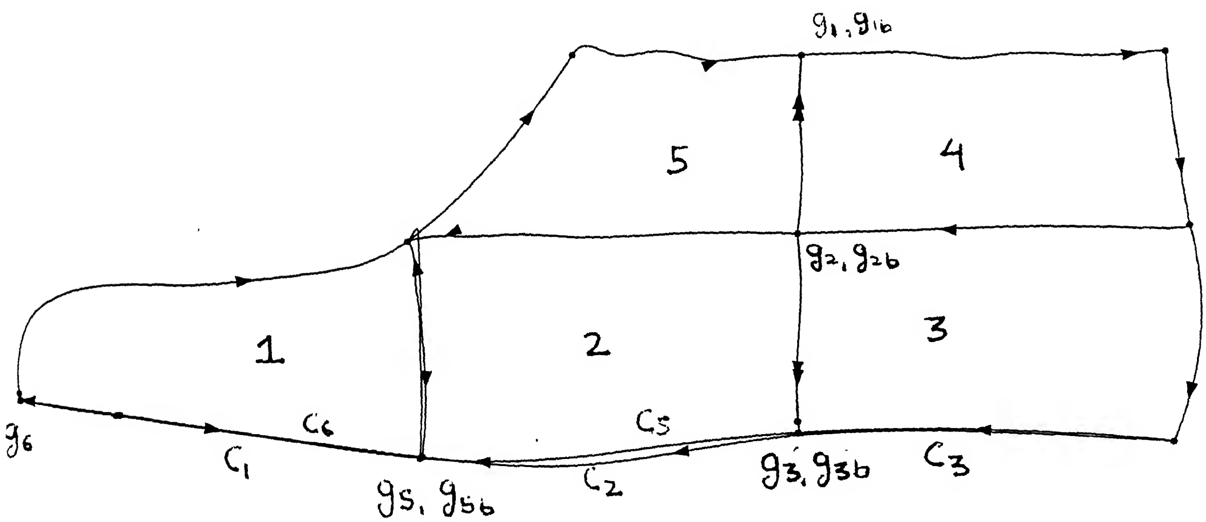


Fig. 3.4 Identification of Points for Patch Creation



g1, g1b
5
4
1
2
3
g2, g2b
g6
C1
C6
C5
C2
C3
g5, g5b
g3, g3b

3.4 Composite Surface Design

Once the curve definition of all the required curves is obtained. The next task is to fit surface patches on the curves. As cubic splines have been used till now for the required curve mesh it is convenient to use Coon's bicubic surface patch (Rogers and Adams (1990)). Coon's bicubic surface patch uses normalized cubic splines for all four boundry curves. Also multiple coons bicubic patches can be joined along their boundaries with C^1 continuity (Tangent continuity). Coons (1967) and Mortenson (1985) provides the required conditions for joining together multiple bicubic patches in detail.

As required shape variations in surface shape can be done by the designer by manipulating magnitudes of tangent and twist vectors of these surfaces.The surface fitting procedure is described below.

1. A set of bicubic surface patches are created based on the curves are created. The surface patches are shown in Fig. 3.5. The Patches should meet the required position and tangent continuity therefore at intersection points for example point g_2 the where the four surface patches S_2,S_3,S_4,S_5 meet should be constrained in a manner so that it satisfies position and tangent continuity for all the four patches.The designer can manipulate the surface patches with the available degree's of freedom by varying magnitude of twist and tangent vectors.

2. Six surface patches meet at vamppoint hence the six surface patches should have C^0,C^1 continuity at vamp point.

3. The surface patches are fitted on the curves on the bottom portion of the last. The patches should have position and tangent continuity among themselves, but they need to have only position continuity with the curves which are on the featherline.

Chapter 4

DEVELOPMENT OF DOUBLY CURVED SURFACES

4.1 Developablity

If a surface is developable, it can be unfolded or developed on to a plane without stretching or tearing by a succession of small rotation of the surface about the generating line.

To determine if a surface of a portion of a surface is developable, it is necessary to consider the curvature of parametric surface. At a point P on a surface if a plane containing the normal **n** intersects it, the curvature of the resulting curve is denoted by k (Fig 4.1). As the intersecting plane is rotated around the normal **n** the curvature changes. It is found that unique directions exist for which the curvature is minimum or maximum. The curvatures in these directions are called the principal curvature, k_{min} and k_{max} . Also the principal curvature are always orthogonal to each other.

Two derived curvatures from the principal curvatures are of particular interest:-

Average curvature $H = \dfrac{k\,\mathrm{min} + k\,\mathrm{max}}{2}$

Gaussion curvature $K = k\,\mathrm{min} * k\,\mathrm{max}$

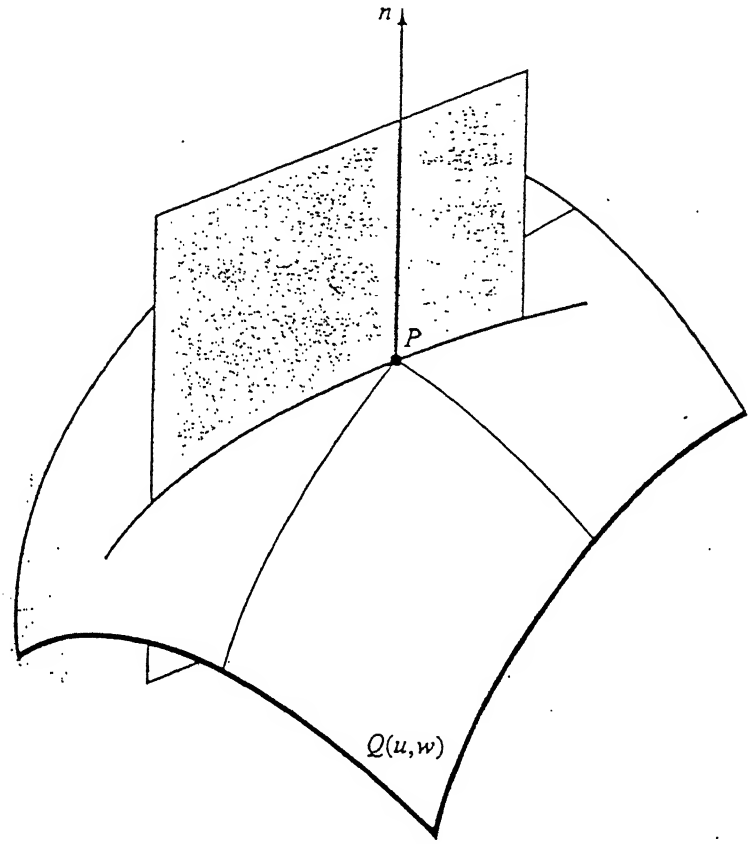


Fig. 4.1 Curvature of a biparametric surface

For a developable surface Gaussion curvature K is everywhere zero.

4.2 Doubly Curved Surface

If a constant or variable curve is moved along another curve then a doubly curved surface is obtained. A doubly curved surface is non developable and can not be developed on to a plane without stretching or tearing. As mentioned before a shoe last comprises of complex surfaces, almost all the surfaces are doubly curved. The upper tightly encloses the last and hence the upper is also composed of doubly curved surfaces. The patches of the upper are not mathematically developable and hence flat pattern development of these surfaces becomes a significant problem.

4.3 Methods For Development Of Doubly Curved Surfaces

The problem of creating planar development of 3D surfaces with double curvature is very commonly encountered problem in product designing. A lot has been done in this area and still more working is going on. As the development can never be exact the method used is problem dependent to a large extent. The way of generating a plane pattern of a general 3D surface depends on the shape of the surface and the material of the cover. For this reason, the way of deriving the development of Airplane's wing will defer from that of leather upper of shoe or from a garment of woven fabric. Taking into account these factors, alternative methods and techniques should be considered for deriving the pattern of 3D surfaces in order to find most suitable technique for each specific case.

The methods to flatten a nondevelopable 3D surface can be broadly divided in to two categories:

1. Flattening after polygonizing the surface , which approximates a surface with planar facets.

2. Flattening directly through developable surfaces.

4.4 Methods To Flatten the Polygonized Data

In this approach the given surface is first approximated with set of planar facets and the subsequent calculations are performed on this approximated surface. This approach can be further categorized in to several models

a) Elastic model
b) Inelastic model
c) Optimization model

4.4.1 Elastic model

In this approach the surface is assumed to be having a degree of elasticity, so that the final plane pattern (that has no gaps or overlaps) can be deformed to fit on the 3D surface. Models are developed by taking in to account stiffness of the material.The surface is approximated with planar triangle facets.

Basic Principle

Strain energy of a triangular facet can be given approximately by $E_n=0.5*F\Delta l$, where Δl is the change in length of edge strut between the length on the original curved surface to the length in flattened surface.The total energy required to force the pattern to assume the required flat pattern from the 3D surface can be used as a yard stick to measure developability.

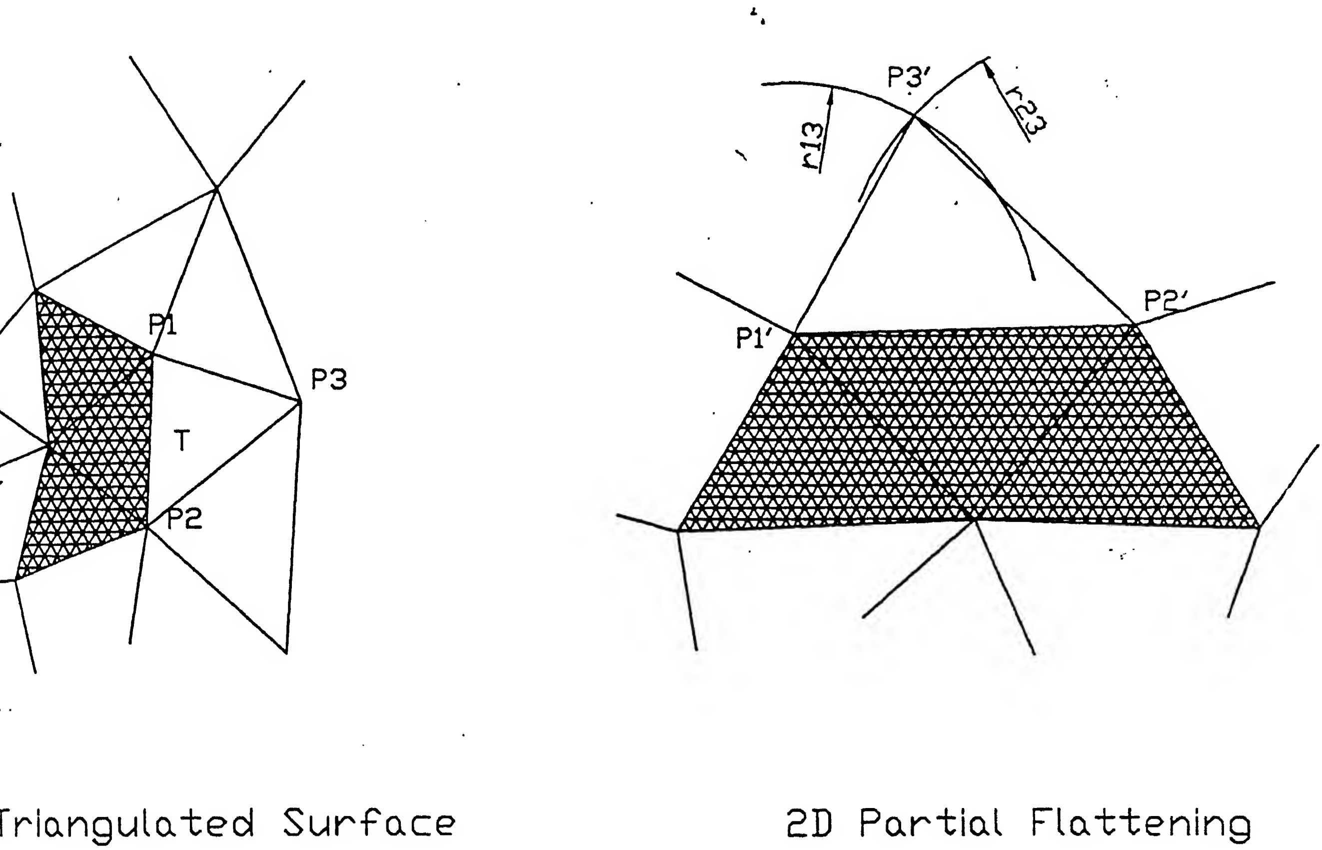


Fig. 4.2 Unconstrained Flattening

General Algorithm

1. Obtain the list of triangles from the triangulated surface.

2. Flattening is initiated by detecting the triangular polygon that is located closest to an averaged position with in the surface, this is called the seed triangle.

3. A search is made for all triangles, which share's a common edge with the seed triangle and these triangles are then subsequently flattened.(if they are not already flattened). The flattening can be of two types.

   a) Unconstrained triangle flattening

   This type of flattening occurs when in triangle $P_1 P_2 P_3$ edge P_1P_2 has already been flattened , while the third node P_3 is yet to be located on the flattening. The position of P_3 on 2D flattening P_3' is found by finding the intersection of two arcs with centers at P_1' and P_2' and radii r_{13} and r_{23}, where r_{13} and r_{23} are the lengths of the appropriate edges on the original 3D surface (Fig 4.2). As the edges on the 2D plane have the same length as the edges on the 3D surface, no distortion occurs, and therefore no energy is added to the existing energy distribution.

   b) Constrained triangle flattening

   This type of flattening occurs when a triangle T shares common edges with two previously flattened triangles. As can be seen from (Fig 4.3) b' is already availaible and b" could be found in the same manner as it was found for unconstrained flattening. The resultant point on the plane will be the mean of these two.

During the flattening process described above the edges will require to be strained; this accumulates an intrinsic energy distribution throughout the material which will reflect

the local departure from the developable property that the surface will embody. Hence if the triangulated surface is close approximation to a developable surface the magnitude of energy distribution will be very small. Excessive tensile strains will indicate tearing and excessive compressive strains will indicate wrinkle or buckling.

4.4.2 Inelastic Model

The most generalized method (Parida and Mudur (1993)) is to first triangulate the surface and then unfold them on to a plane. The unfolding process then entails

1) Identifying a start (seed) triangle.
2) Transforming one of its neighbors, i.e a triangle having a common edge with it, to the plane of start triangle. The transformation involves a rotation about a common edge; this unfolding is carried out further until all the triangles have been brought to the plane of first.

The paper presents algorithms that have been implemented to obtain planar developments of complex surfaces with cuts and overlaps only in specified orientation. This inelastic model is specially useful in case of fibrous materials where the manufacturing process of composite laminates is such that the elasticity of the material cannot be considered.

4.4.3 Optimal Flattening Algorithm

In this method a given surface is first approximated by polyhedron mesh and subsequently a variational problem is formulated in which goodness of fit criteria is optimized.

Basic Principle

A variational problem is formulated in which we maximize the goodness of fit of the "distance matrix" of the original 3D model and its flattened 2D model. The distance matrix here is defined as the matrix of all possible interpoint distances. Thus in a polyhedron model of a surface , the distance between node i and node j is (given by d(i,j)) is the interpoint distance and is defined as the minimum geodesic distance along the paths embedded in the surface. This ensures that there will be a sensible match between straight line distances in the plane, and the corresponding minimal geodesic distance on the curved surface.

In the (unknown) flattened model, the same nodes i and j have unknown distance between them, which we term dij. A quantity L can be defined which represents least square measure of fit , between the metric structure of the original polyhedron and its corresponding planar model. It is given by

$$L=\frac{1}{C}\sum_{j=1}^{N}\frac{(dij-Dij)}{dij}$$

Where $C=\sum_{j=1}^{j=N} dij$

Finding the minimum interpoint distance between two points on a polyhedron mesh is a very difficult problem to solve. Good flattening occurs only when, large distance;neighborhood (large N)is used. By large distance neighborhood we mean that the distance matrix consists of many neighbors of a point. This is achieved at the expense of increasing computational time appreciably.

4.5 Flattening through Developable Surfaces

In this method, a complex free form surface is approximated by set of piecewise developable surfaces and then these developable surfaces are unrolled on to a plane

individually. The approximate flattened surface can then be fabricated by assembling these sets of developable surfaces in their proper location.

Basic Approach

We can approximate a given freeform surface by a set of disjoint (except along boundaries) piecewise ruled surface. All members of the set are then checked for developability because all ruled surface are not developable. The condition for developability is given in Faux and Pratt(1983). If all members of the set are found to be developable the approximate development of freeform surface could be performed.

Let S(u,v) be a general Bspline surface which is divided in v parametric direction such that

$$C_1=S(u,v_{min})$$

$$C_2=S(u,v_{max})$$

Are isoparametric curves at v_{min} and v_{max}.

and R be the set of ruled surface between curves C_1 and C_2 and $R_1(u,v)$ is the representation of R(u,v) in the same Bspline basis as that of S(u,v). It is worth noting that $R_1(u,v)$ can be obtained from R(u,v) by appropriate degree raising and refinement(Cohen et al.(1986)), (Cohen et al.(1980)).

Algorithm

Ruled Surface Approx(S, τ)
{

If (max Distance (S,R_1) < τ

Return R_1

Else

Subdivide S(u,v) in to two subsurfaces S_1 and S_2 along v.

Return

}
Ruled surface Approx (S_1,τ)
Ruled surface Approx (S_2,τ)

End

The approach provides us with a technique to decompose a freeform model into its corresponding developable model. Not every freeform surface can be exactly represented using piecewise developable surfaces. However the approach introduced allows us to construct a piecewise developable surface approximation to an arbitrary freeform surface with tolerance control.

This methodology can be extended to support stretching and tearing ,which will enable us to deal with arbitrary surfaces(which cannot be exactly decomposed into piecewise developable surfaces). Then the technique could be used for handling fabric and other anisotropy materials.

4.6 Proposed Method For Development

As mentioned before the method which is used for development is problem dependent and the approach adopted should be suitable for the specific case. The method for this study needs to be implemented for development of surfaces of a last and the material to be used is leather. The leather has a property of stretchability, and thus by stretching the leather appropriately the leather patch can be made to almost fit the reasonably complex surfaces of the last. Thus provision for darts and gussets need not be implemented.

We have tried to incorporate traditional method of pattern development in to computerized form in this approach. Traditionally a shoe maker uses geodesics to cut patterns, by drawing lines on the shape of shoe; these lines become the edges of the flattened 3D patterns. To determine the pattern of a region the shoe maker sticks a paper strip on a median curve of the region to flattened. He then cuts the sheet from this line in fine “fish bones”; each of them is folded back to the shoe form, determining a geodesic on the surface. Finally the trace of the region border is marked on each fishbone giving him the edge of each flattened zone. In our approach the idea has been taken from this traditional approach and we use isoparametric as cut lines. Starting from a given curve, we develop the shoe surface until deformation threshold is reached.

As we are using Reverse Engineering and obtaining the surface patches from the last definition, it is not necessary that we will have the complete mathematical information about the surface patch. This is because many of the existing CAD software’s do not

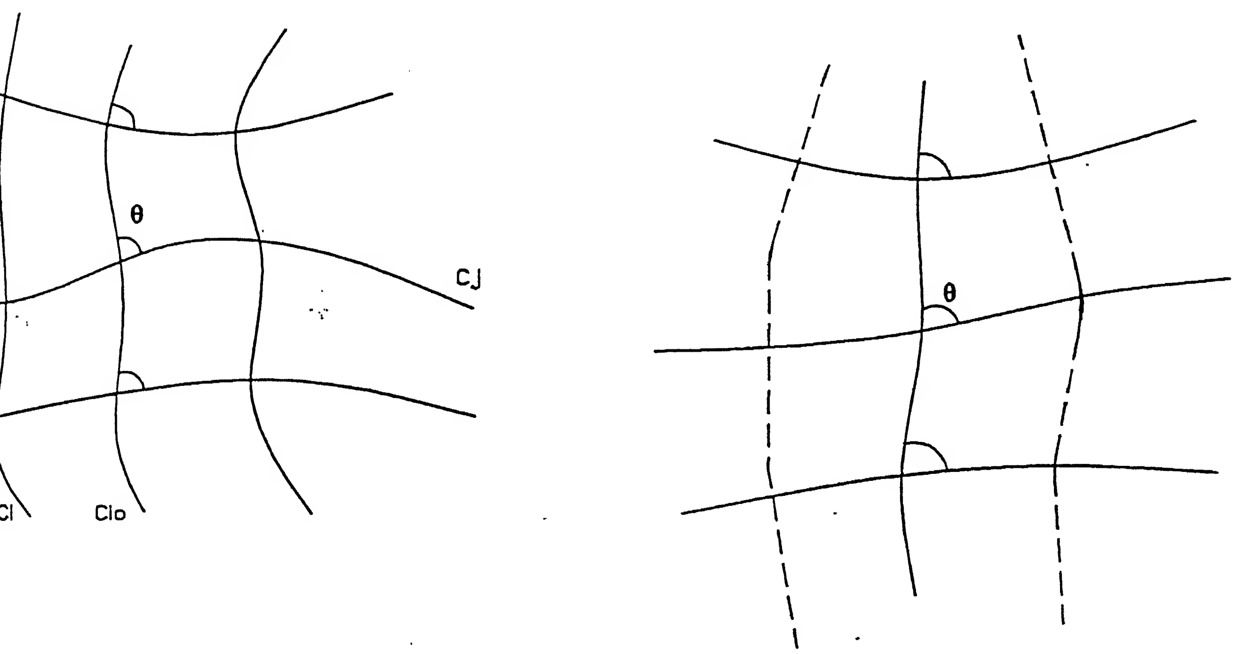


Fig. 4.4 Geodesic Curvature Preservation Flattening

provide user with complete surface definition of a surface. In such cases the proposed approach is very useful and quick.

4.7 Methodology Of Present Approach

The present work introduces a relatively new technique for interactive piecewise flattening of parametric 3D surfaces, leading to nondistorted texture mapping. A dense isoparametric grid is first generated on the surface to be developed and the flattening algorithm is based on this isoparametric sampled grid. The flattenig of the region grows around a isoparametric curve selected by the user. A distortion criterion is introduced to control and stop the development when the accumulated distortion exceeds a previously determined threshold. The flattening method is based on results of differential geometry, more precisely on the notion of "geodesic curvature ". Isoparametric curves of the surface are mapped in constructive way to the corresponding curves on the plane with preservation of geodesic curvature at sample points and with arc length (i.e chord length preservation) (Fig. 4.4).

General Algorithm

1. Map the initial selected curve C_{io} of the surface ($u=u_{io}$) on to a curve on the plane with geodesic curvature preservation at sample points and arc length preservation. (distance preservation between any pair of successive ample points).

2. Extend step by step development of the isoparametric curves on the left side of C_{io}. While mapping transversal curves C_j on to the curves on the plane with arclength and geodesic curvature preservation , one also requires preseravtion of cross angle between the initial curve C_{io} and each transversal curve C_j . The process is stopped

when the left side distortion threshold is reached or curve C_i belongs to an already flattened region.

3. Extend the development on the right side of C_{io} according to the righthand side threshold (same procedure as the left side one).

Note that distances are preserved along the initial curve C_{io} and in the transversal curve C_j. All distortions are concentrated on the curves C_i parallel to C_{io}.

4.8 Mapping A 3d Surface Curve on to a Planar Curve with Arc Length and Geodesic Curvature Preservation.

Suppose the curve C (Fig. 4.5) that we want to map on to the plane contains n+1 sample points Mi, (i=0..n) and let us denote by $\mathbf{n}_i$ and $\mathbf{T}_i$, respectively the normal vector and the tangent plane to the surface at point Mi . The curve flattening algorithm can then be described as follows:

1. Map the first curve segment M_0M_1 on to a segment P_0P_1 in plane such that $d(M_0 ,M_1)=d(P_0 ,P_1)$. It is sufficient to fix an initial point P_0 and a direction on the plane.

2. For each j, $2<j<n+1$, P_j is iteratively computed in the plane as follows.

   Project M_j and M_{j-2} on to the tangent plane to the surface at M_{j-1}. This provides two points in T_{j-1}, called $M1_j$ and $M1_{j-2}$ and given by the formulas:

   $$M1_j = M_j + ((M_{j-1} - M_j).\mathbf{n}_{j-1})\mathbf{n}_{j-1} .$$

   $$M1_{j-2} = M_{j-2} + ((M_{j-1} - M_{j-2}).\mathbf{n}_{j-1})\mathbf{n}_{j-1}$$

3. Use dilation in T_{j-1} to transform M_{1j} on to a point $M2_j$ such that

   d(M_{j-1},Mj)=d(M_{j-1},M2j).

   $M2_j = M_{j-1} + (\| M_j - M_{j-1}\|) / (\| M1_j - M_{j-1}\|) * (M1_j - M_{j-1})$

4. As P_{j-2} and P_{j-1} are already computed, the desired point P_j is the point on flat plane that preserves simultaneously the angle θ_{j-1} between $M1_{j-2}$ M_{j-1} and M_{j-1} $M2_j$, and the distance d (M_{j-1} , $M2_j$).

5. The way we obtain P_j is to first compute coordinates (x1,x2) of $M2_j$ according to local orthogonal frame (M_{j-1}, $\mathbf{e_1}$,$\mathbf{e_2}$) in $\mathbf{T}_{j-1}$ where

$$\mathbf{e_1} = (M_{j-1} - M2_{j-2})/ (\| M_{j-1} - M2_{j-2}\|)$$

$$\mathbf{e2}= \mathbf{n}_{j-1}\, X\, \mathbf{e_1}$$

$$x1= (M2_j - M_{j-1}).\mathbf{e_1}$$

$$x2= (M2_j - M_{j-1}).\mathbf{e_2}$$

P_j is the point of flat plane having the same coordinates according to the orthogonal and positive frame (P_{j-1}, r_1, r_2) given by

$$\mathbf{r_1}= (P_{j-1} - P_{j-2})/ \|P_{j-1} - P_{j-2}\| = \mathbf{ai} + \mathbf{bj}$$

$$\mathbf{r_2}= \mathbf{r_1}\, X\, (0\mathbf{i}+0\mathbf{j}+1\mathbf{k})$$

$$P_j= P_{j-1} + (x1\mathbf{r_1} + x2\mathbf{r_2})$$

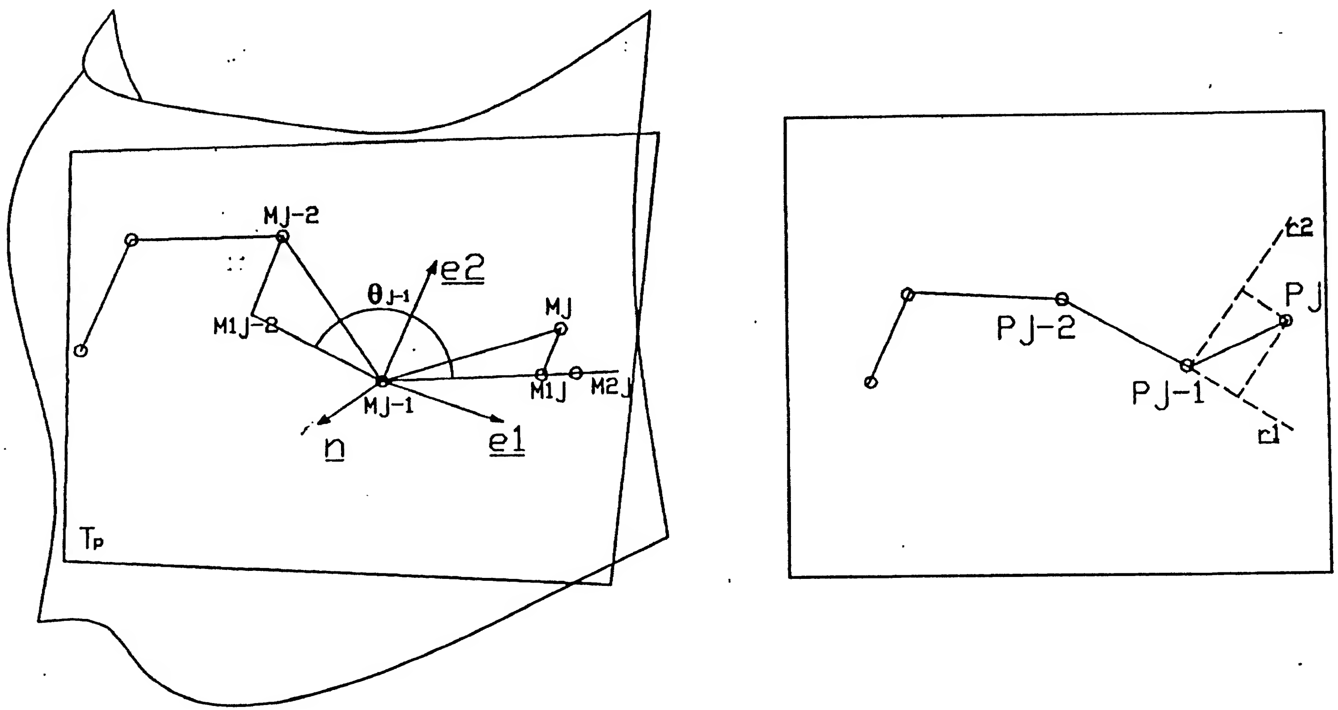
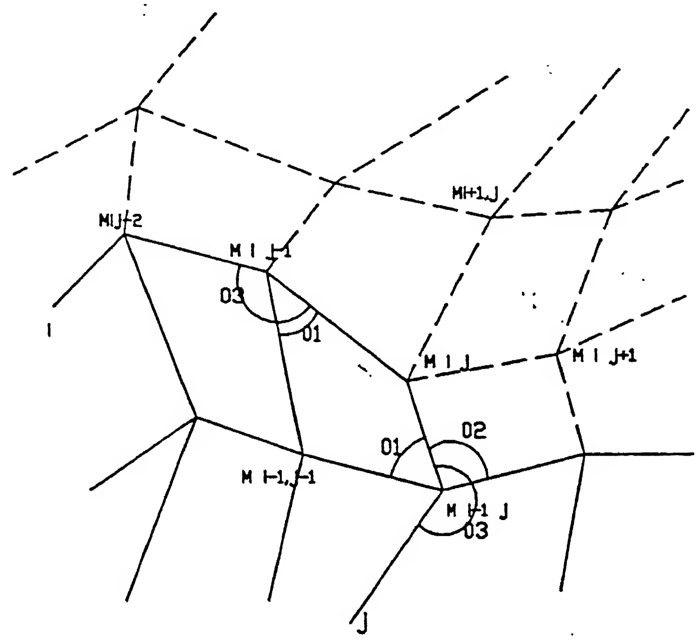
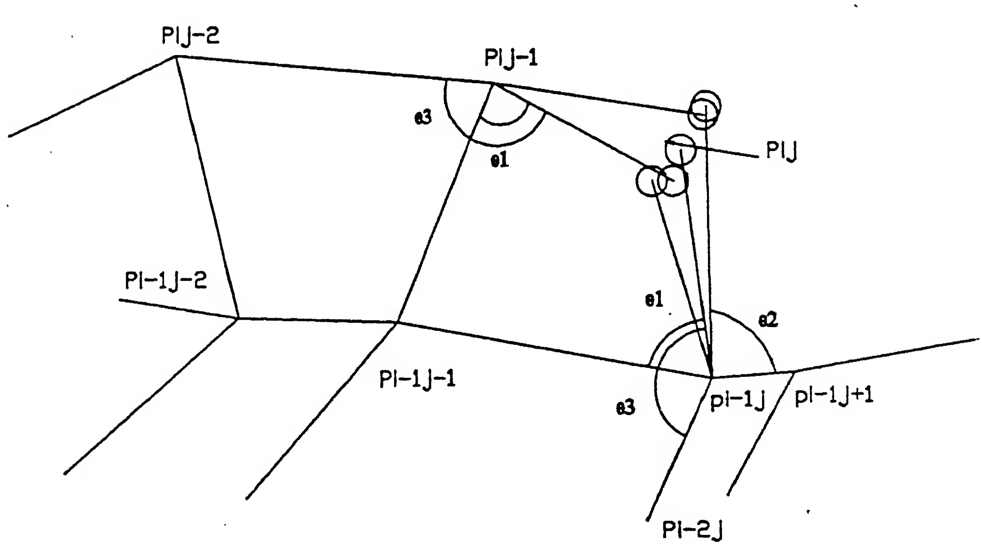


Fig. 4.5 Mapping a curve of a surface on to a planar curve


MI+1,J
MIJ-2
M I J-1
03
01
I
M I J
M I J+1
01
02
M I-1,J-1
M I-1 J
03
J


PIJ-2
PIJ-1
e3
e1
PIJ
PI-1J-2
e1
e2
PI-1J-1
e3
pI-1J
pI-1J+1
PI-2J

4.9 Incorporating Geodesic Curvature In Both Directions

The technique described in this section consists of distributing distortions in both directions , unlike in the previous technique (preservation of geodesic curvature in only one direction), where all the distortions are concentrated on the curves parallel to the initial curve. This technique is implemented in two steps:

1. One first develops the surface around the initial curve, taking in to account at each point the geodesic curvature in both directions u and v and the corresponding projected cross angles. This development induces a gradient of distortions on the flattened region. This gradient enables one to measure the distortions and stop the development propagation when necessary

2. A relaxation procedure is than used to reduce and uniformly distribute the distortions in the flattened region.

Development Technique

The new development algorithm is almost the same as the algorithm of the previous section. One first maps the initial curve C_{io} on to the plane with geodesic curvature and arc length preservation. The development of the region is then step by step propagated to curves parallel to curve C_{io} , ie on the left hand side of curve C_{io} and then on the right hand side of C_{io} . The new feature introduced here is the way in which the points of these curves are mapped on the plane.

As shown in the Fig. 4.6, let M_{ij} be the point being processes and let it be the point of intersection of C_i and C_j. P_{ij} is obtained by preserving at each neighbour $M_{kl} \in \{ M_{i-1\,j}, M_{i\,j+1}, M_{i+1\,j}, M_{i\,j-1} \}$ which are already processed, the three angles ($\theta1_{kl}$, $\theta2_{kl}$, $\theta3_{kl}$). $\theta1_{kl}$ and $\theta2_{kl}$ are cross angles (facing M_{ij}) between the curves that intersect at M_{kl}. Preserving $\theta3_{kl}$ is equivalent to preserving the geodesic curvature at M_{kl} on the curve containing M_{ij} and M_{kl}. As one can not always preserve all the three angles as some of the points may not have been processed yet, also each angle preservation provides a different point in flattened plane. The resultant point is then the centroid of all these points obtained. For each point M_{kl} there can be at the max twelve points (three from every neighboring point) that can be obtained (if all the four neighboring points are already processed). Also note that for a mathematically developable surface each angle preserver provides us with the same point, whereas for other surfaces choice of centroid induces slight errors on the angles and the distances. The accumulation of these errors provide s us a gradient of distortion in the scanning direction. So, for a better distribution of distortions the curve being processed may not be scanned from one extreme position to another extreme position, instead the curve is scanned from one central point on the initial curve to other external points.

With this technique distortions are present in both C_i and C_j curves. The distortions increase in diagonal directions as one gets far from the central point of the initial curve.

Relaxation Procedure

In the above development, when mapping a point on to the flat flattening plane, one does not take in to account all the neighboring points. The reason being that some of the neighboring points have not been processed yet. In addition for a given neighbor one can not always preserve all the three angles. The relaxation procedure consists of recomputing the points of the obtained flat piece several times until the change becomes insignificant. At each iteration one uses the results of the previous iteration.

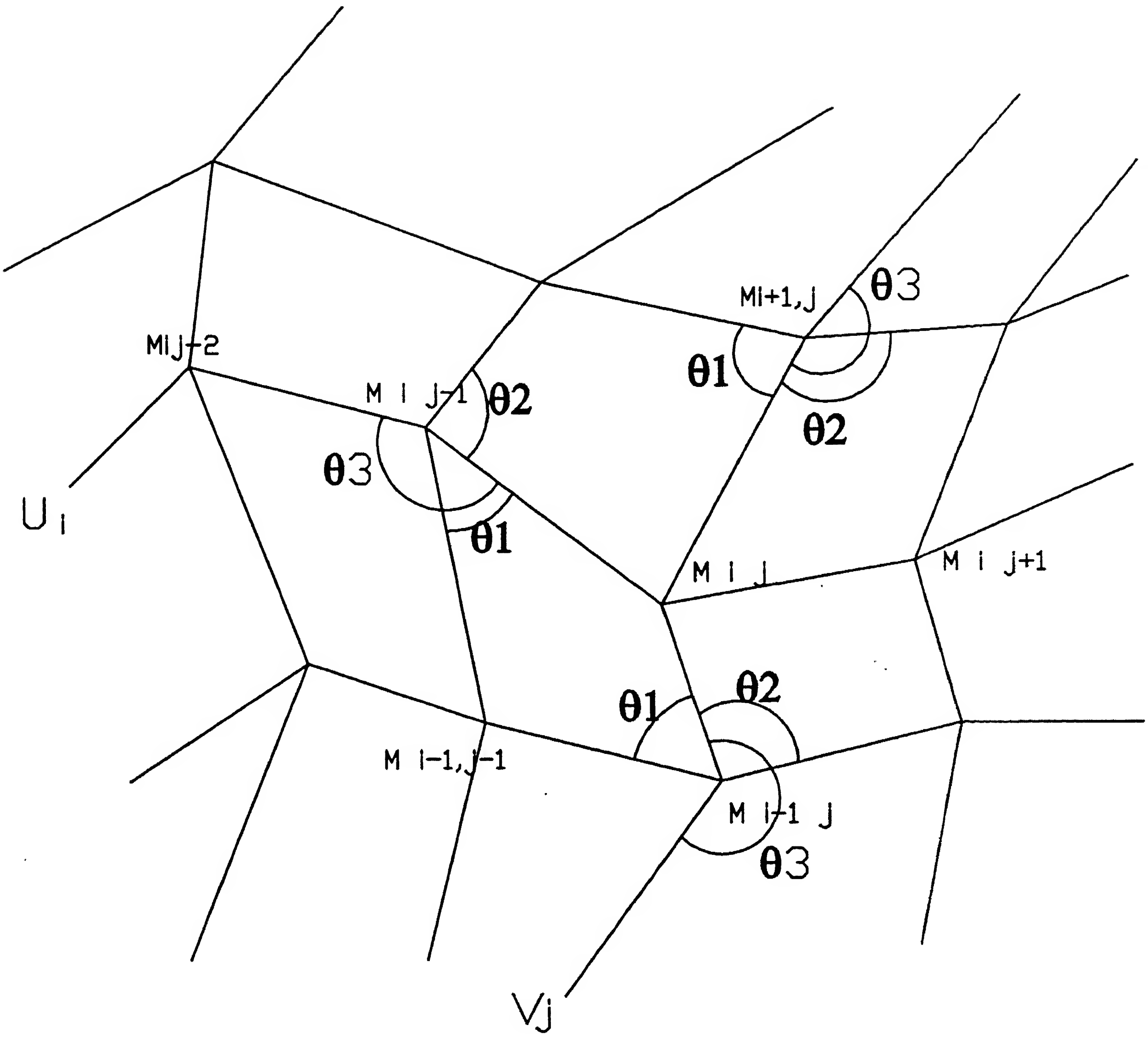


Fig. 4.7 Relaxation Process

The location of point $P^{n}_{i\,j}$ at iteration n is then obtained by taking centroid of the twelve points (Fig 4.7) obtained by preserving the three angles of each neighbour.

Chapter 5

IMPLEMENTATION AND EXAMPLES

The software programs are developed in C language and have been interfaced with I-deas (Master Series 6A). Programs have been written for geodesic curvature preservation in one direction and for geodesic curvature preservation in both the direction. The programs are user friendly, the grid density and the initial curve can be chosen by the user conveniently. The curved surface's which need to be flat-patterned can be either directly constructed using the standard menu options of the I-deas or they can be imported in to I-deas through any standard import procedures.

Two cases have been studied in detail :

1. An ellipsoidal surface has been considered and flat-pattern developments of this surface are analyzed in detail.

2. A shoe last and development of its surfaces.

5.1 ELLIPSOIDAL SURFACE

A CAD model of an ellipsoid is prepared and a rapid prototype is made of one eight of the ellipsoid. The rapid prototype is made so as to physically try out the developments obtained. Figure 5.1 shows the ellipsoidal surface of the CAD model. The flat-pattern development is carried out by two methods :

1. Development with geodesic curvature preservation in one parametric direction.

2. Development with geodesic curvature preservation in both the directions.

5.1.1 Geodesic Curvature Preservation in One Parametric Direction

Figure 5.2 shows the ellipsoidal surface along with the isoparametric lines. Number of isoparametric curves in u and v direction are forty each. The isoparametric curves are marked by U and V in the figure.

The development of ellipsodal surface about U_3 parametric direction has been shown in Fig. 5.3. U_3 is the initial curve, shown with an arrow in the figure, along which geodesic curvature as well as arc lengths are preserved. The projected cross angle is preserved between the initial curve U_3 and the cross curves V_i. All the v direction curves preserve geodesic curvature and arc lengths. The error gets accumulated as we move away from the initial curve U_3 because we are not able to preserve geodesic curvature and arc length along the isoparametric curves parallel to U_3. Figure 5.4 shows the development of the same surface but the initial curve in this case is U_{12}.

The most appropriate development is obtained when the initial curve is taken as U_{20} as can be seen in Fig. 5.5(a) and Fig. 5.5(b), this is because this isoparametric curve lies on the center of the surface and the error propagation is minimum on both the sides of this curve(the error is spread over maximum area). The development around the curve U_{35} is shown in Fig. 5.6. In this case also the development is very accurate near the U_{35} curve but becomes highly inaccurate as we go away from this curve.

In fig. 5.7 the development has been performed along V_{20} curve, in this case there is a change in direction of the isoparametric curve and hence the development is accurate near the V_{20} curve.

5.1.2 Preserving Geodesic Curvature in Both Direction

In this approach,development is based on preservation of geodesic curvature and arc lengths in both the parametric directions as explained in Section 4. The development in this case is not highly dependent on the choice of initial curve, but it is still dependent on the initial curve to some extent. The development obtained is examined on the ellipsoidal surface shown in Fig. 5.8. The surface has 20 isoparametric curves in both u and v directions. Fig. 5.9 shows the development of the surface when the development is around the initial isoparametric curve B_2. The error propagates as we move away from curve B_2 but the propagation error is comparatively less than that of the case when geodesic preservation is done in one direction because the distribution of error is along both u and v direction. The development along B_{10}, with geodesic curvature preservation in both direction and with relaxation technique has been shown in Fig. 5.10(a). The development obtained is found to be very accurate and is shown in Fig. 5.10(b) along with the ellipsoid.

5.2 DEVELOPMENT OF THE SURFACE OF A SHOE LAST

A shoe last used for making shoes for export to Europe has been chosen for the development. It has been supplied by a shoe manufacturer in Kanpur area. For developing the surfaces of the complete shoe last the surface of shoe last is delineated in to a number of surface patches as shown in Fig. 5.11(a) and Fig. 5.11(b). Infact Figure 5.11(b) is made through reverse engineering using Faro-Arm and it shows point data cloud and various surface patches of the last. Figure 5.12 shows surface patches on the surface of the last. Surface patch 1b and its scaled development is shown in Fig. 5.13. The development is done by preserving the geodesic curvature along one direction, shown by the arrow in Fig. 5.13. It is worth noting that the development is done about the center curve of the surface. It has been found that the development is

quite accurate because the surface patch is small. Similarly, Fig. 5.15 and Fig. 5.16 show the to the scale development of the patches 2 and 3. The developments when placed together on the shoe last are shown in Fig. 5.17. It is clear from the figure that the featherline of developed patterns is matching well with the featherline of the shoe last. Also, the common edges of the developed patterns match well with each other, within permissible tolerances.

5.3 DESIGNING OF VARIOUS SHOE STYLE ON A LAST

The designing on the surface of the shoe last is done directly on the screen by placing the surface model of the last in the elevation view and then by doing the designing directly on the screen as shown in Fig. 5.18. The curves created are directly projected on the surface of the last. The boundary curve, which is created for the formation of the collar, can be mapped on the developed flat pattern as shown in Fig. 5.19. The figure shows the mapping of curves of the collar on the patch 3 and patch 4 on their corresponding developments. The curve for vamp formation which lies on surface patch 2 is mapped to its development and is shown in Fig. 5.20.

5.4 CONCLUSION

The results are shown for various cases on an ellipsoidal surface. When the geodesic curvature preservation is done in one direction only it is found that the results of development are very much dependent on the choice of initial curve chosen. The results are found satisfactory when the initial curve chosen is around the middle of the surface.Geodesic curvature preservation was then done in both the directions along with relaxation technique and the results found were also satisfactory. In this case the results were not very much dependent upon the choice of the initial curve.Surface of shoe last was delineated in to number of surface patches and these surface patches

were then developed individually. It was found that the development was accurate if correct initial curve is chosen and if the size of surface patch is not very large. Mapping of a curve on the curved surface to its corresponding flat-pattern is shown in Fig.2.19 and fig. 2.20. The technique can be utilized effectively to obtain patterns with complex profiles.

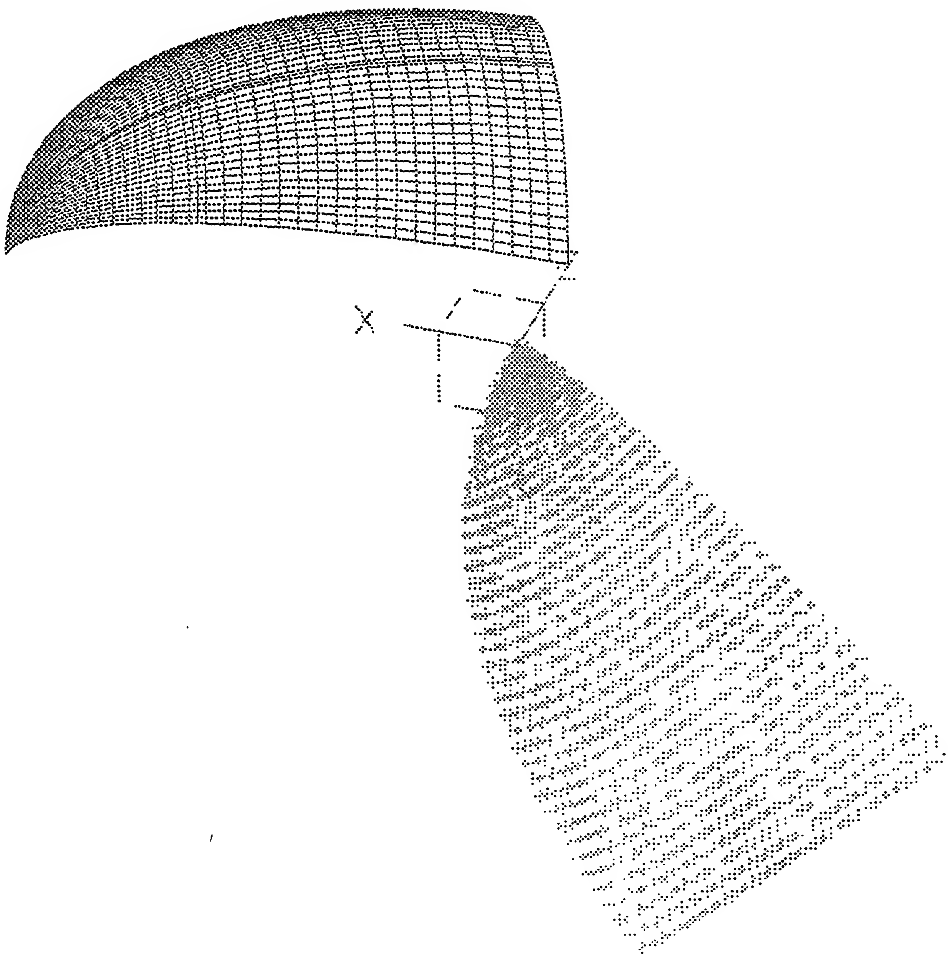


Fig. 5.1 The Ellipsoidal Surface Chosen For Development

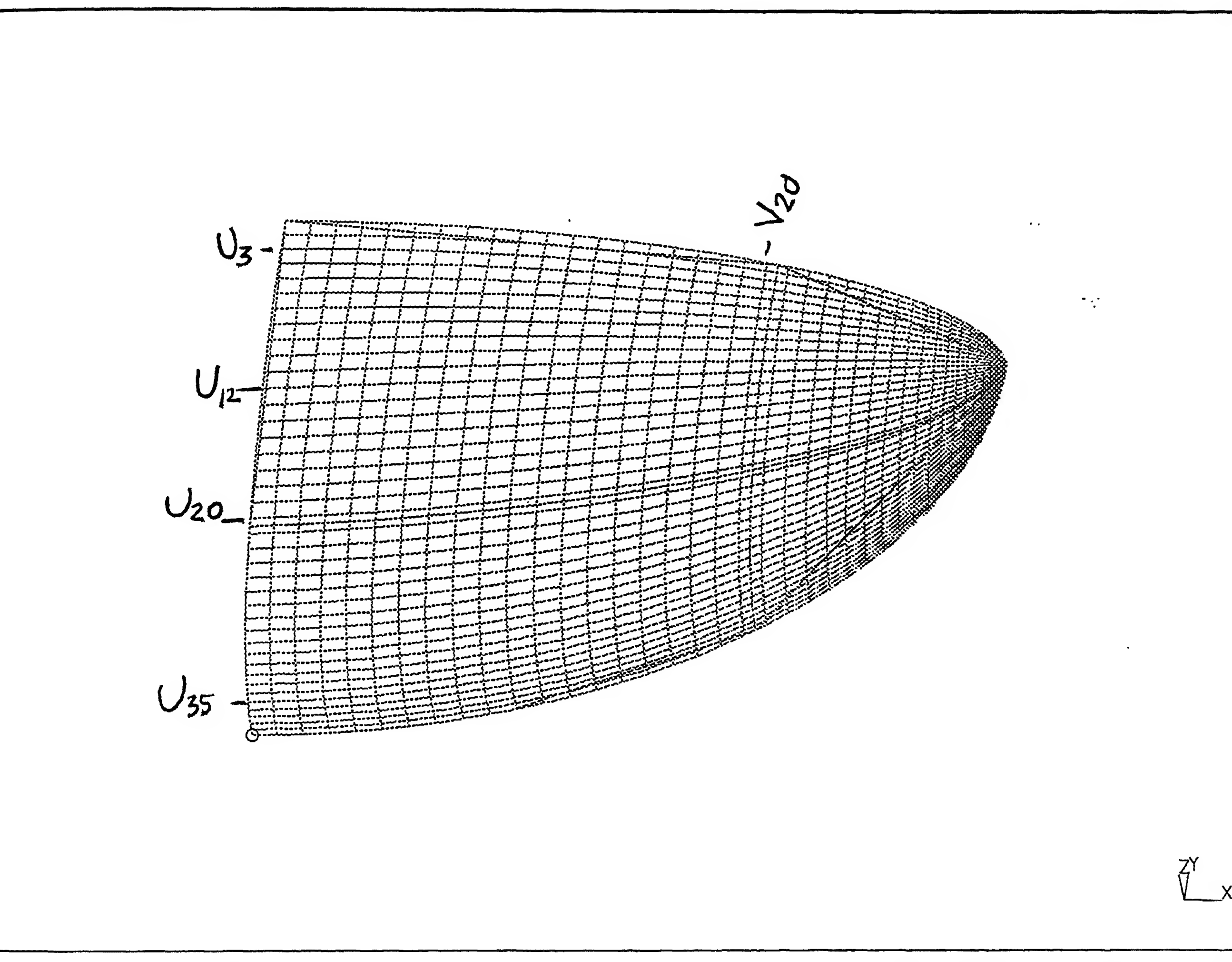


Fig. 5.2 Isoprametric Curves Along Which Development Is Carried Out While Preserving Geodesic Curvature In One Direction (For Fig. 5.4 - 5.7)

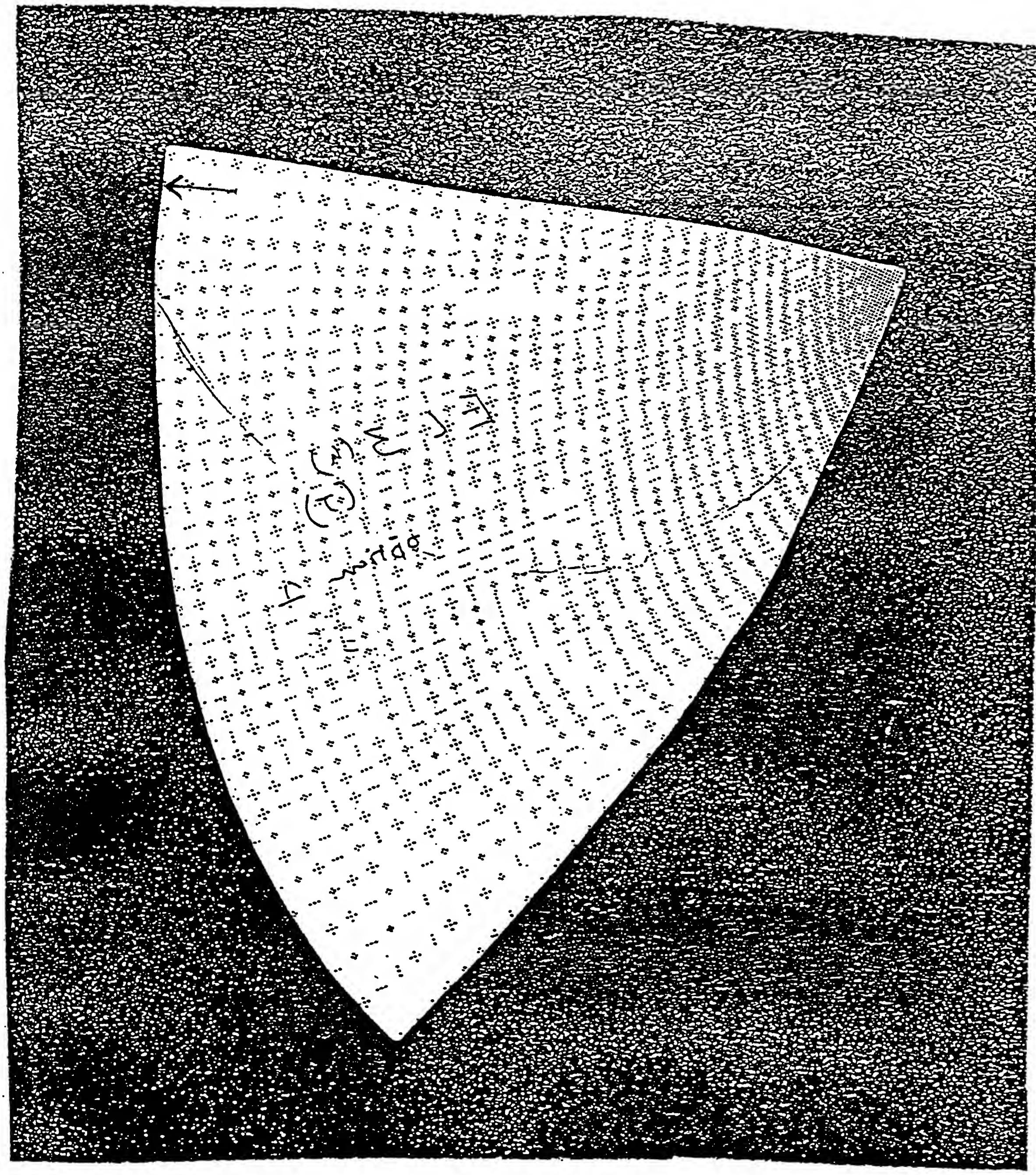


Fig. 5.3 Development Of The Ellipsoidal Surface Along U_3 While Geodesic

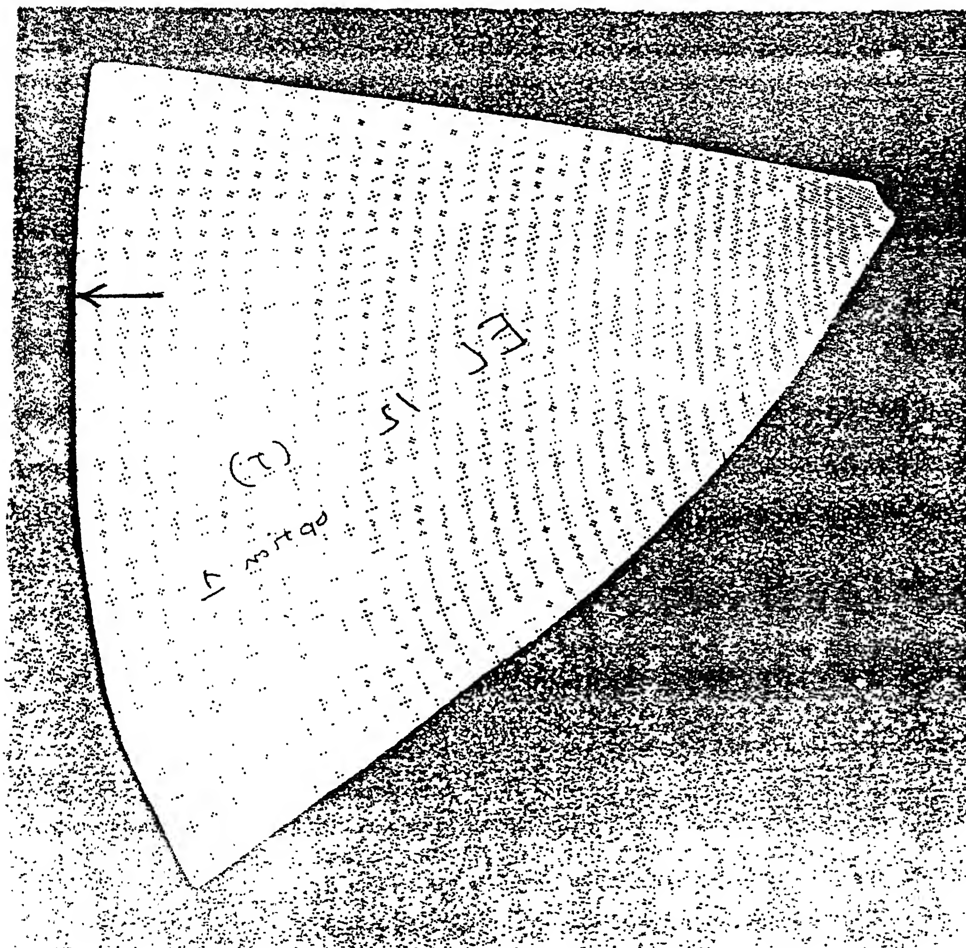


Fig. 5.4 Development Of The Ellipsoidal Surface Along U_{12} while Geodesic

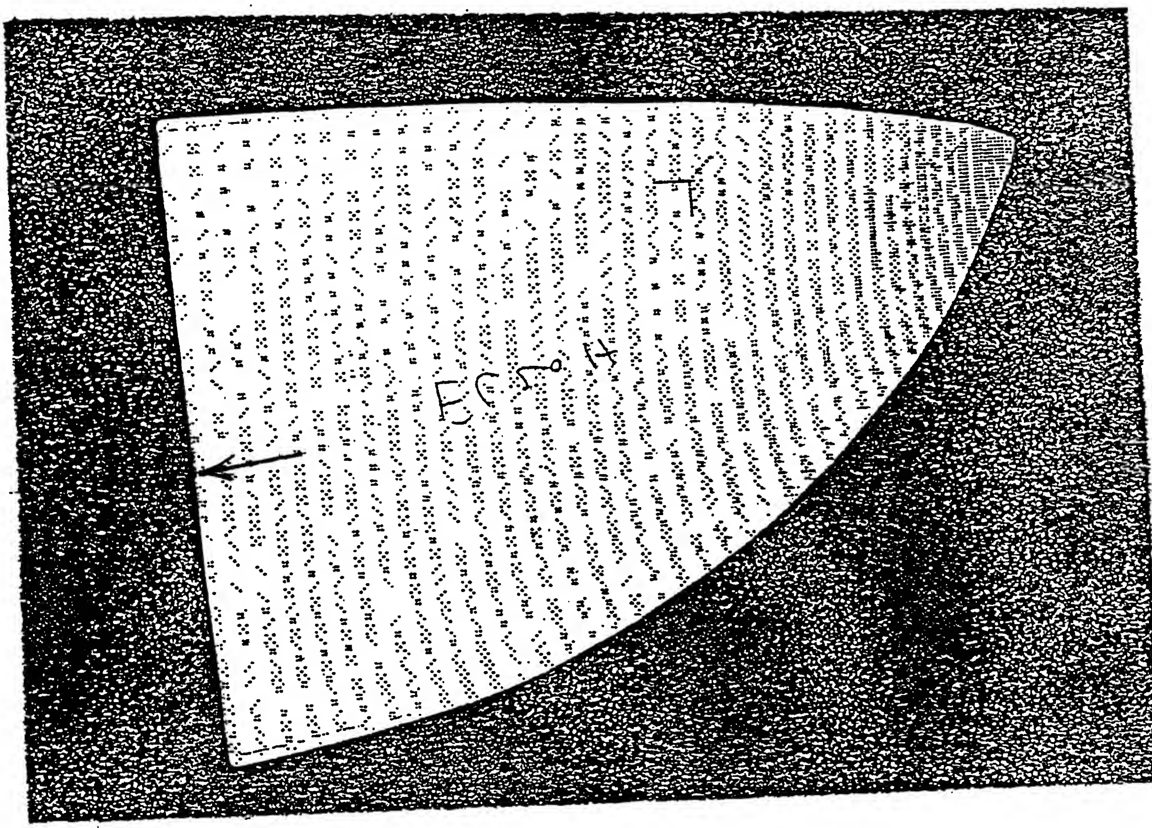


Fig. 5.5 (a) Development Of The Ellipsoidal Surface Along U_{20} while Geodesic Curvature Preservation In One Direction

Fig. 5.5 (b) Photograph Of The Ellipsoid And Its Development along U_{20}

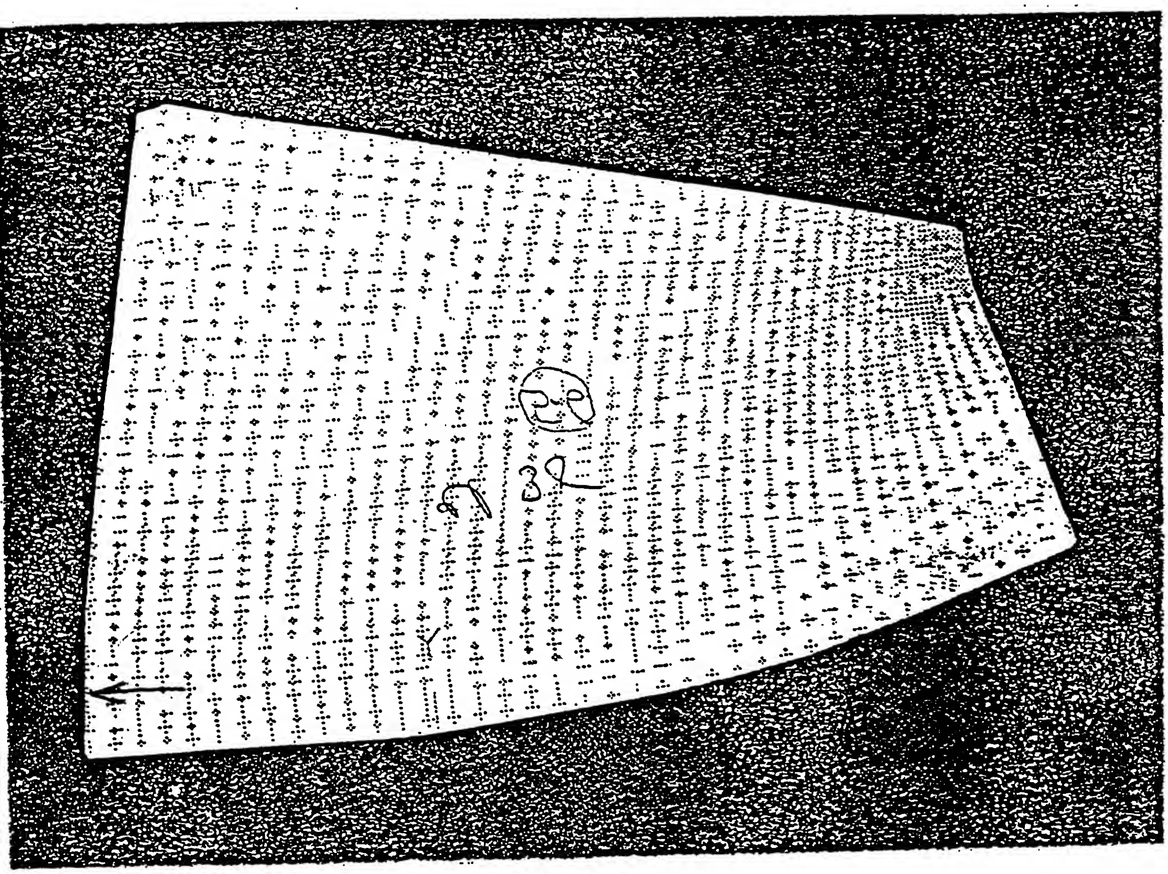


Fig. 5.6 Development Of The Ellipsoidal Surface Along U_{35} While Geodesic

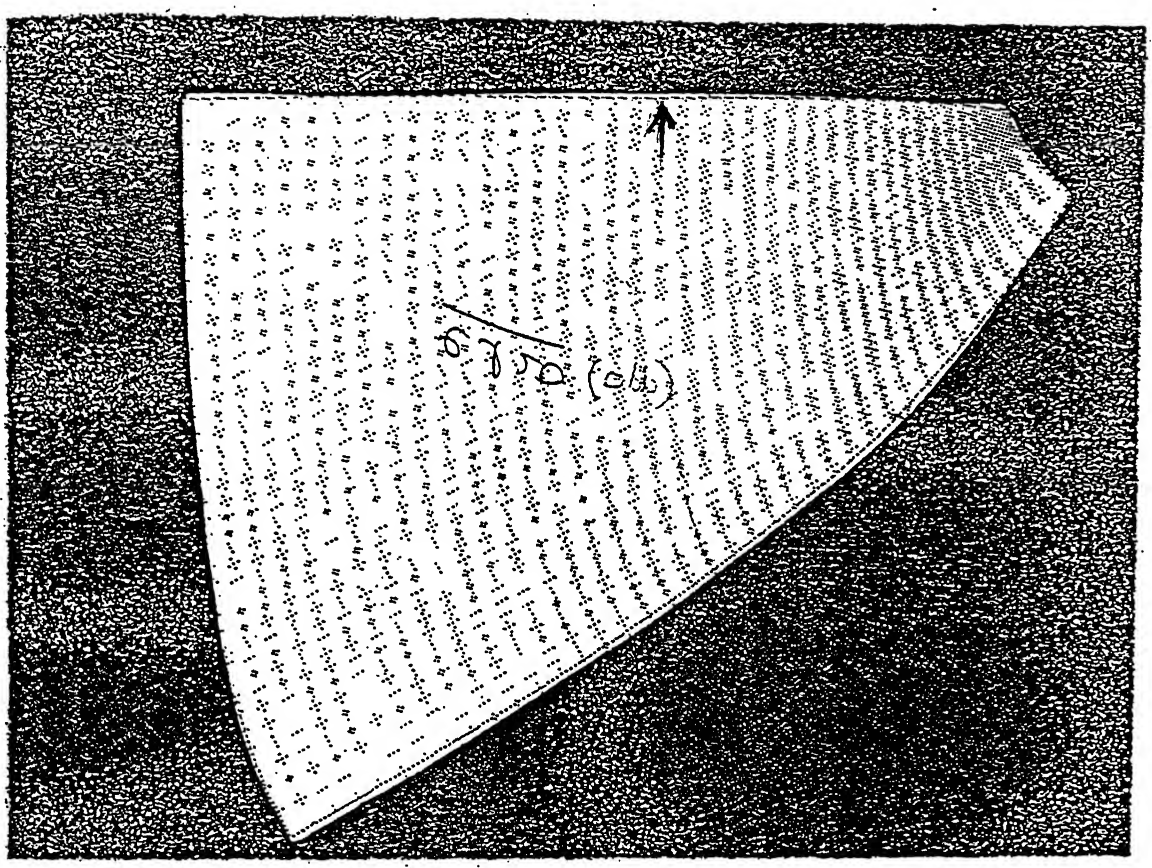


Fig. 5.7 Development Of The Ellipsoidal Surface Along U_{35} while preserving Geodesic Curvature Preservation In One Direction

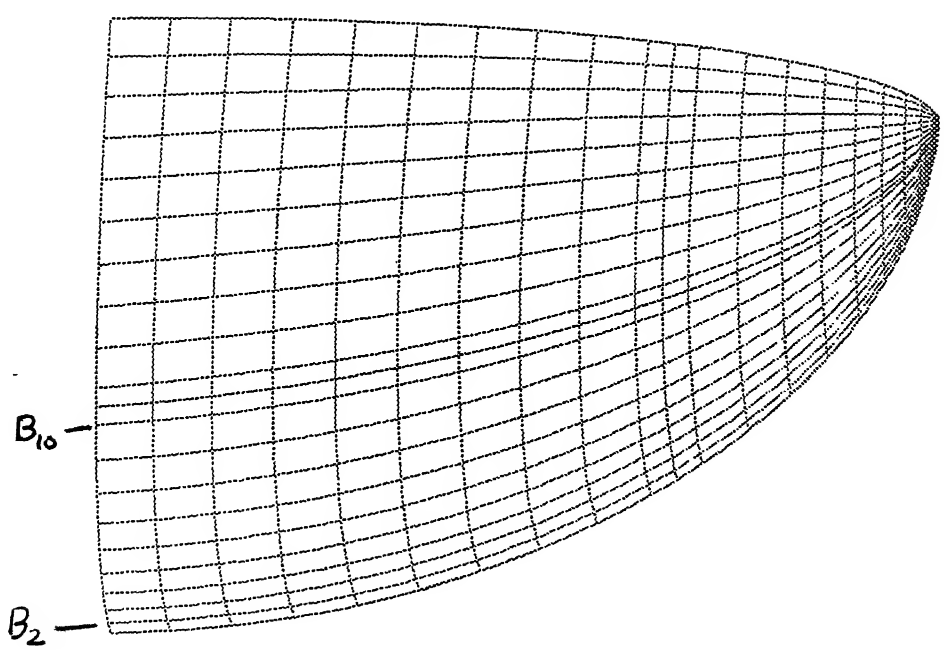


Fig. 5.8 Isoparametric Curves Along Which Development Is Carried Out while Preserving Geodesic Curvature In Both Direction (For Fig. 5.9 -5.10)

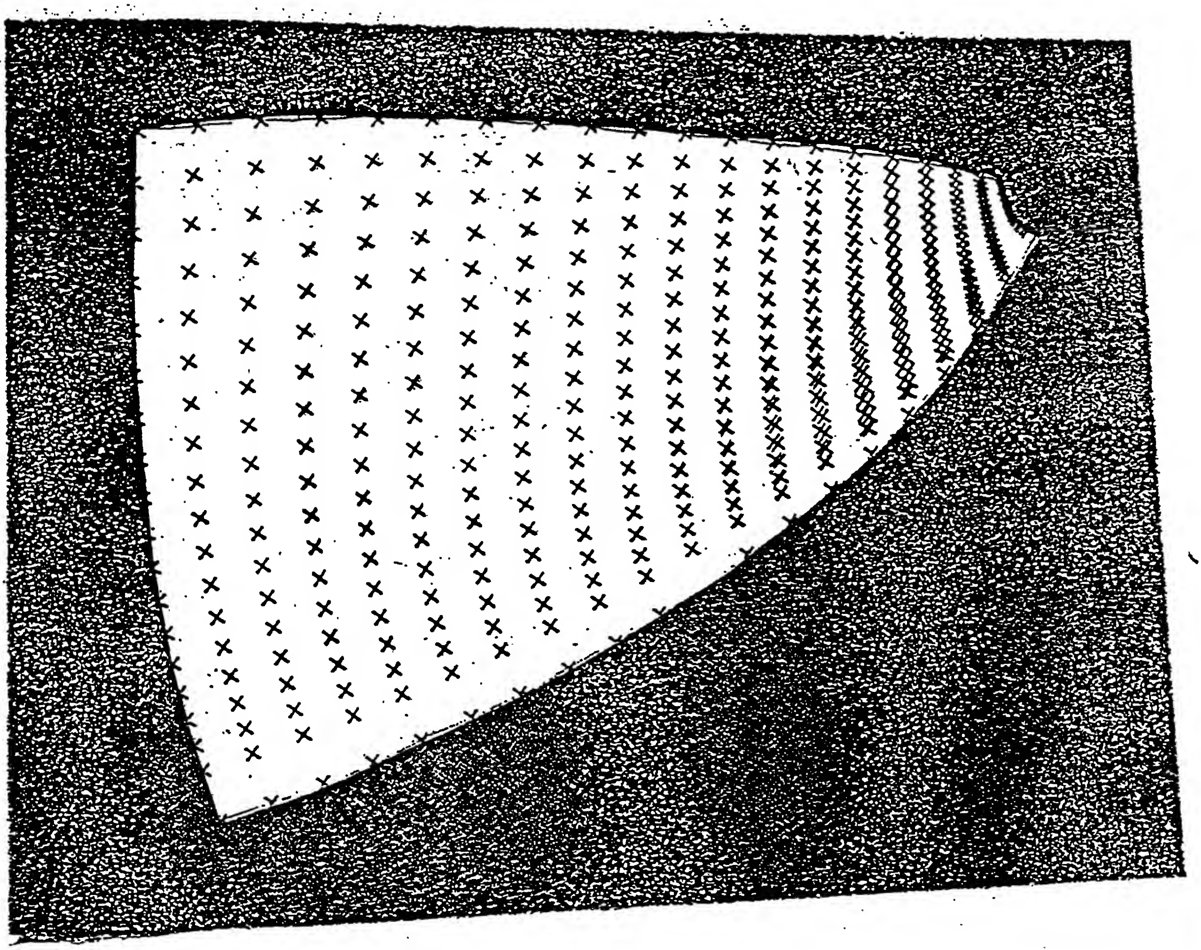


Fig. 5.9 Development Of The Ellipsoidal Surface Along B_2 While Geodesic Curvature Preservation In Both Directions

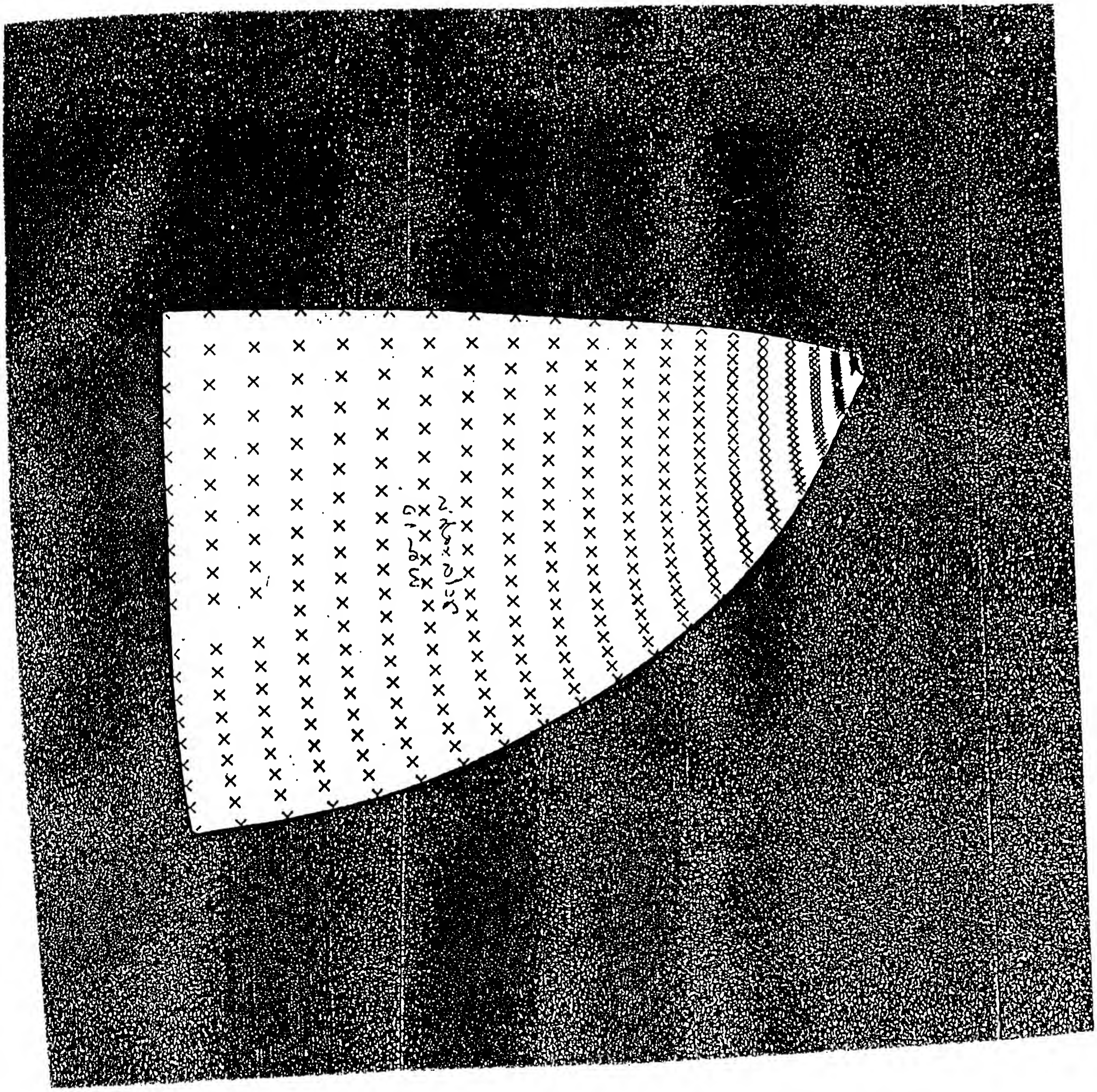


Fig. 5.10(a) Development of The Ellipsoidal Surface Along B_{10} with Geodesic Curvature Preservation In Both Directions

Fig. 5.10(b) Development (along B_{10}) Placed over the ellipsoid

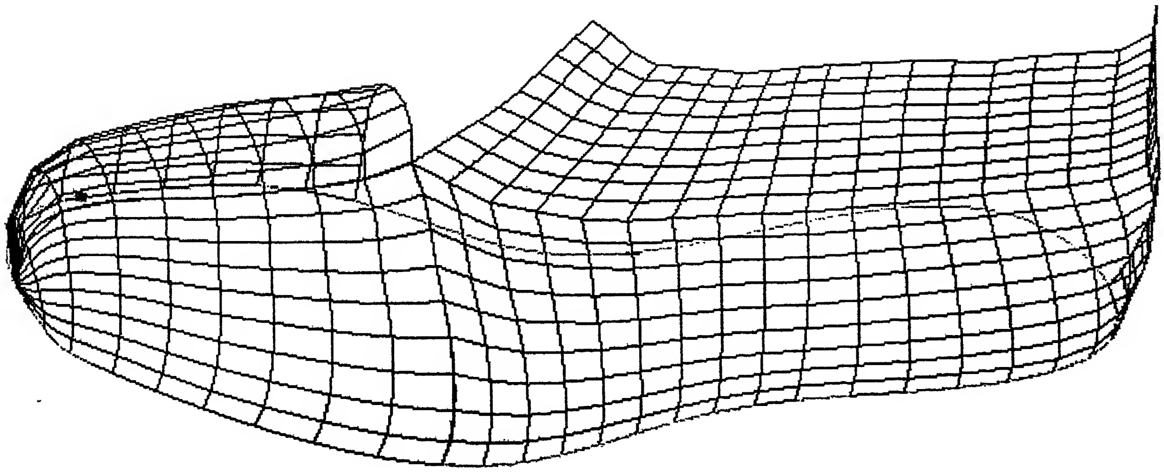


Fig. 5.11(a) Surface Representation of The Shoe Last

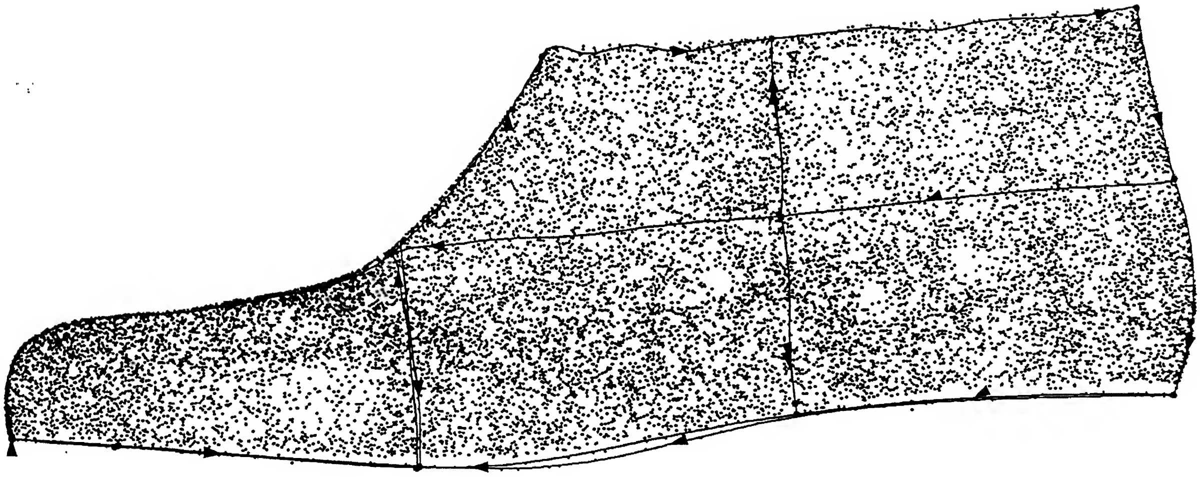


Fig. 5.11(b) Shoe Last Surfaces Divided in to Surface Patches

Fig. 5.12 Photograph Showing Surface Patches

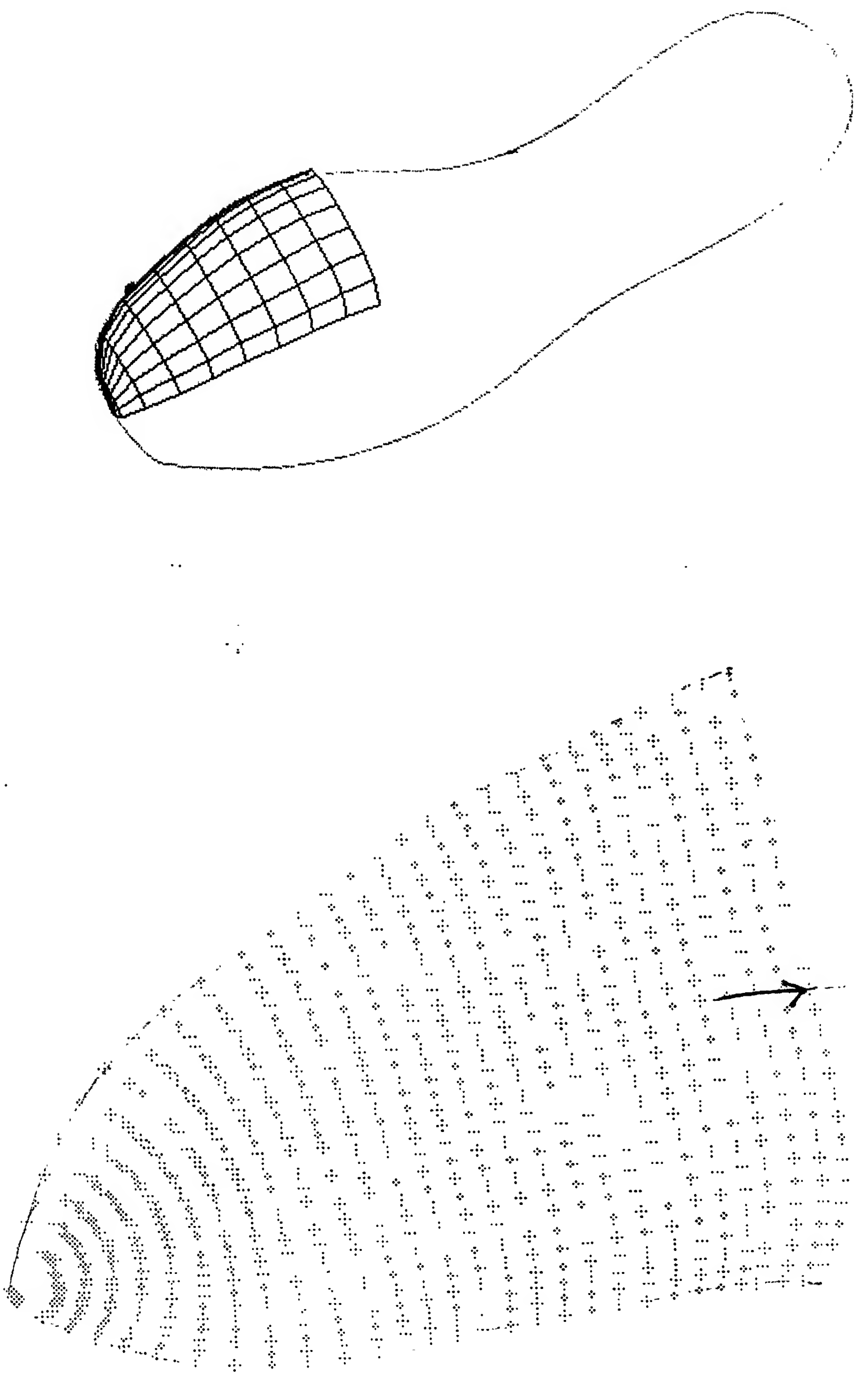


Fig. 5.13 Surface Patch 1b And Its Development

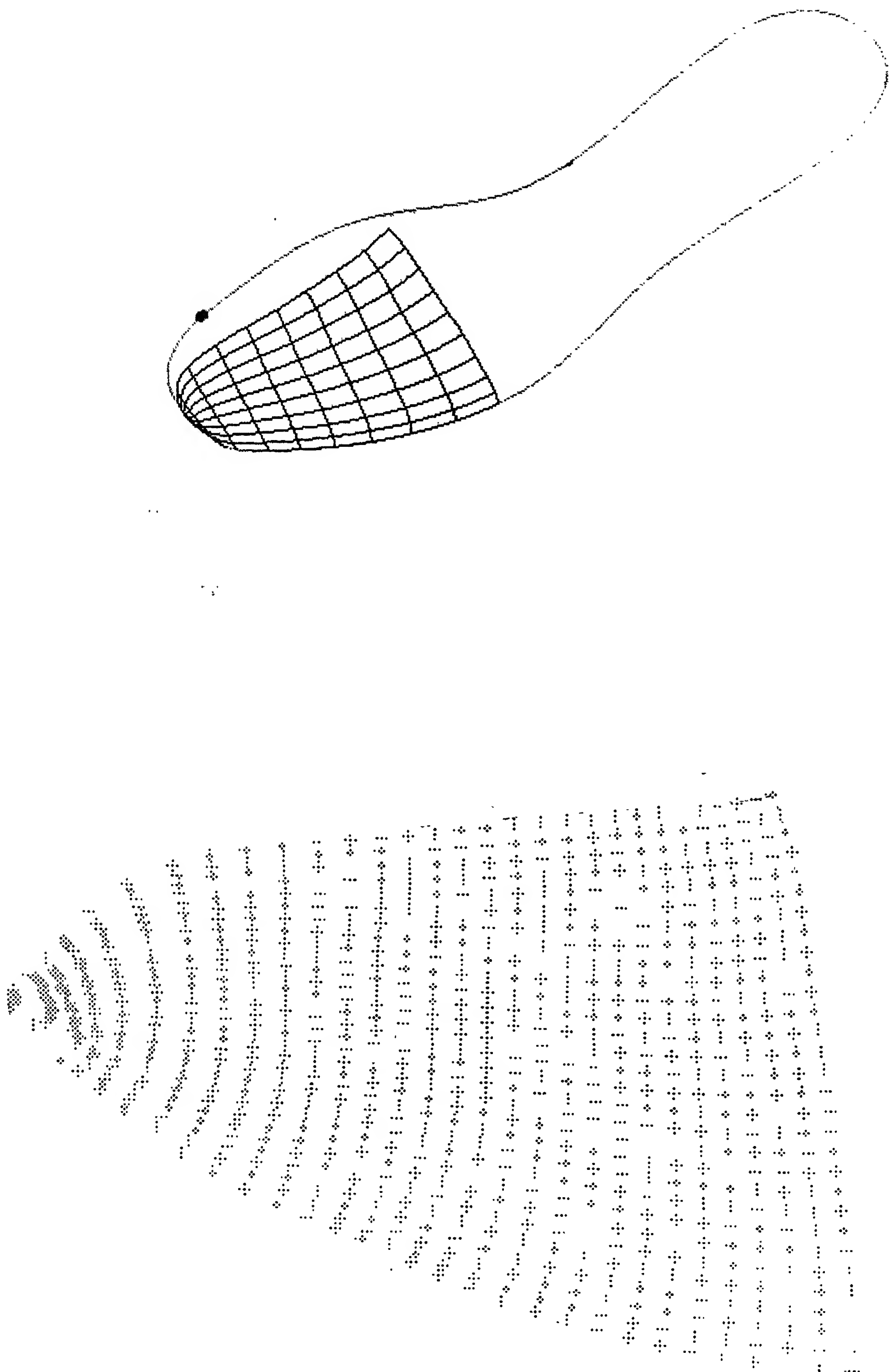


Fig. 5.14 Surface Patch 1 And Its Development

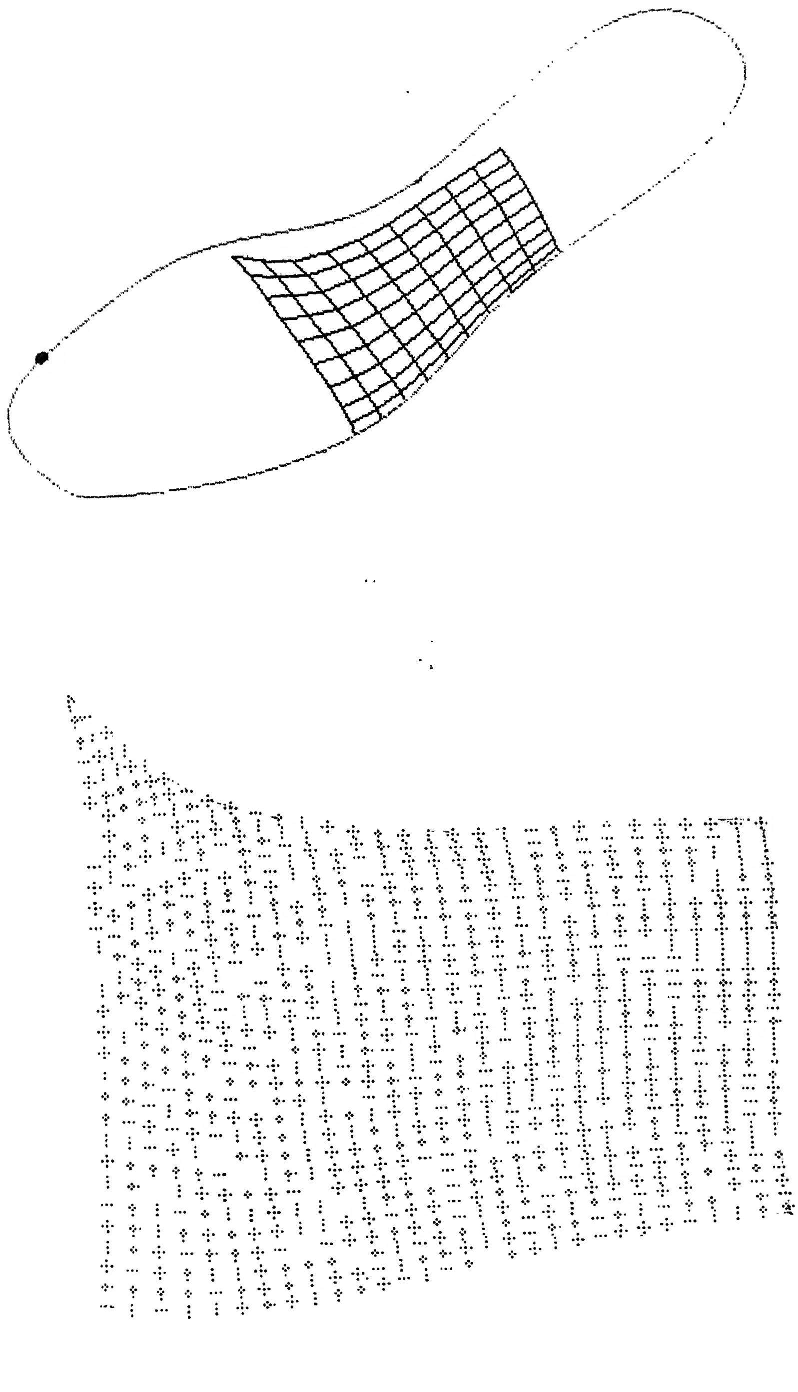


Fig. 5.15 Surface Patch 2 And Its Development

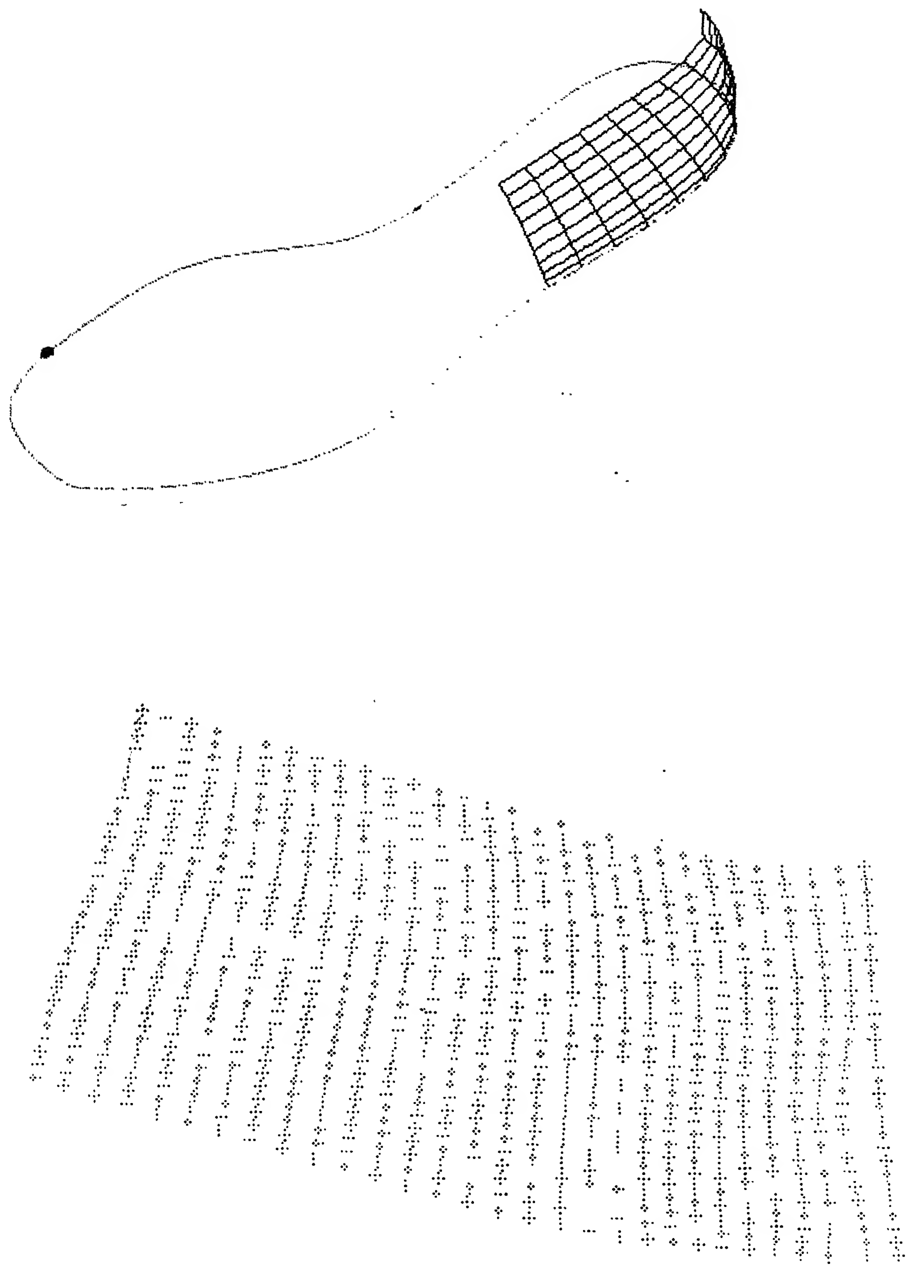


Fig. 5.16 Surface Patch 3 and Its Development

Fig. 5.17 Development of Various Patches Placed on the Shoe Last

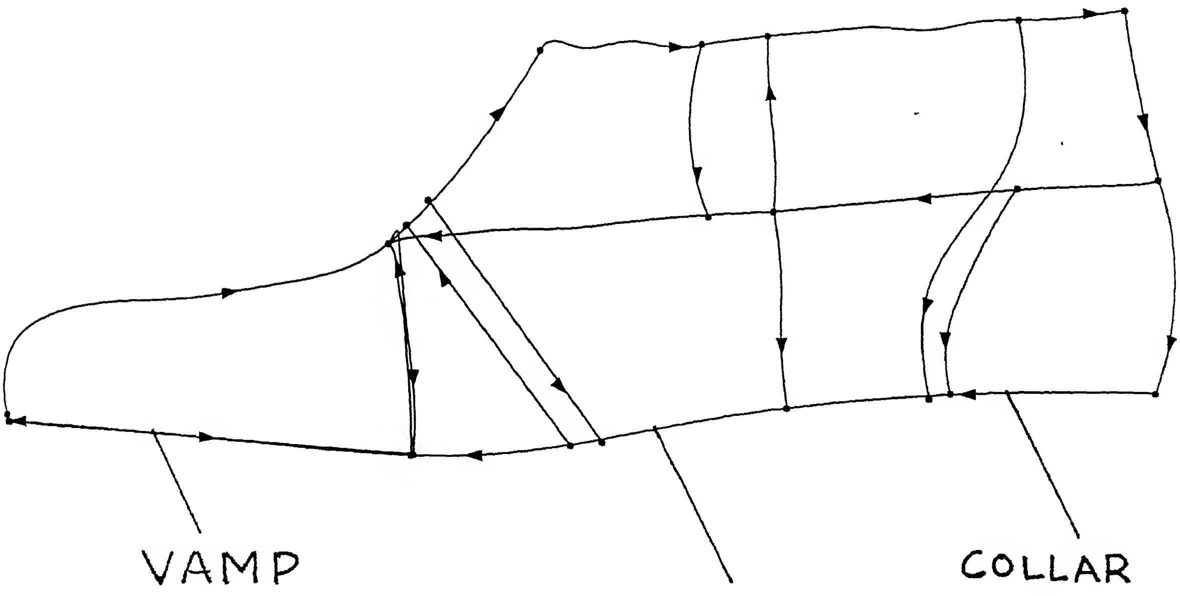


Fig. 5.18 Onscreen Designing Of The Shoe Last

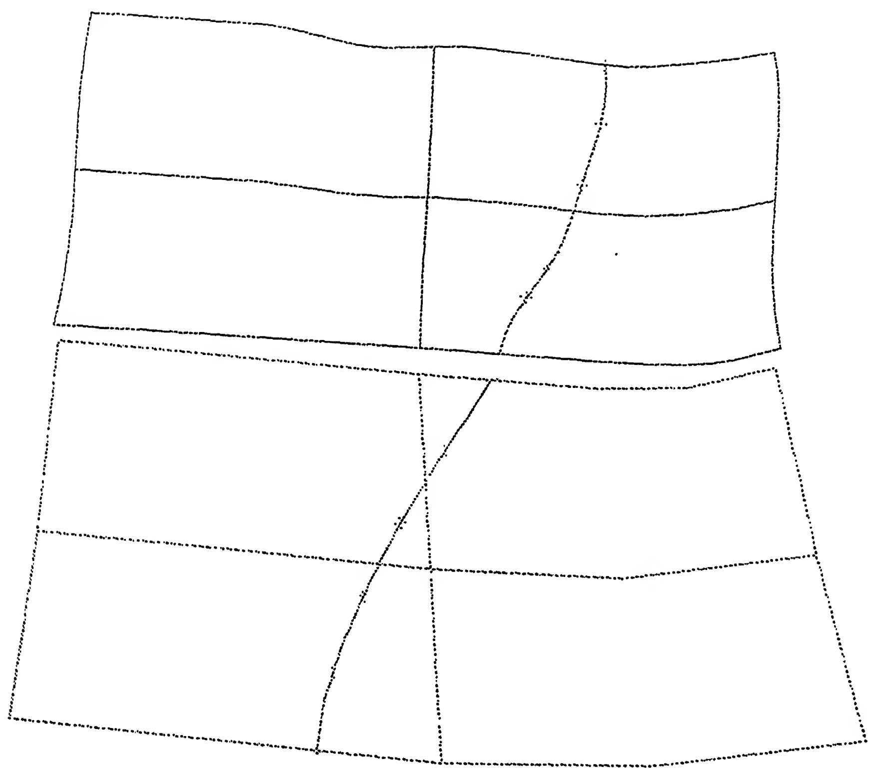
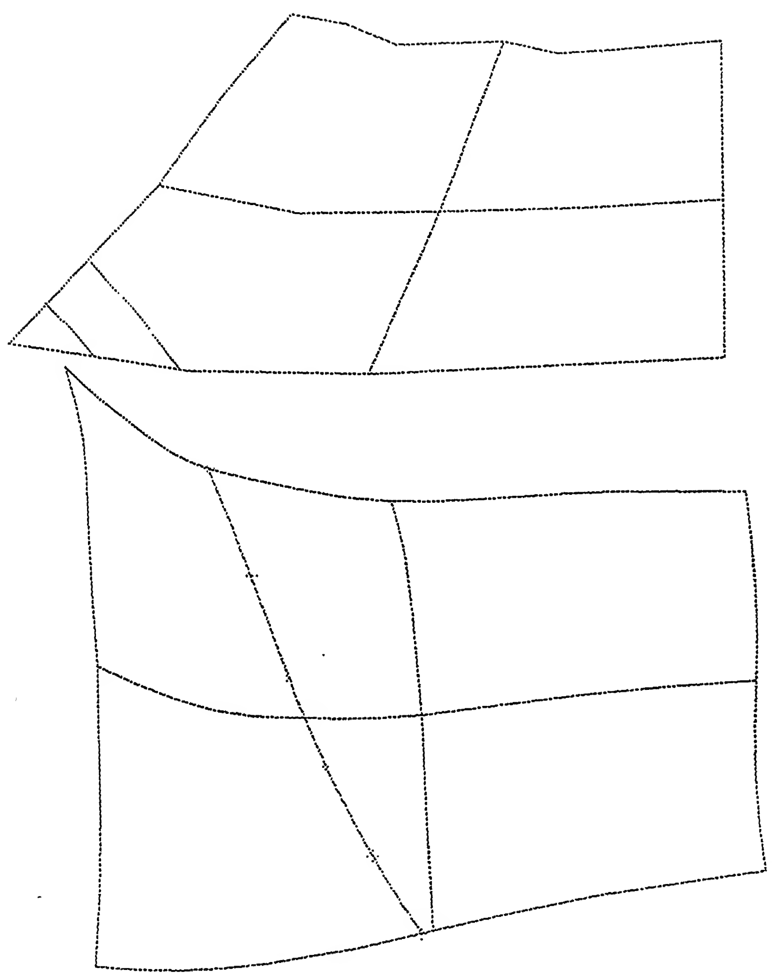


Fig. 5.19 Mapping of Collar Boundary on the Development



Boundary On The Development

Chapter 6

CONCLUSION

6.1 Technical Summary

The development of patterns for a particular style of shoe design has been dealt in this work. The first requirement is the surface definition of the last. The last's surface definition can be obtained either by scanning an existing last or by creating a customized last to meet the requirements. On-screen designing of the shoe style is done directly on the last definition and the flat patterns for this particular style are obtained by development of various selected surface patches of the last.

A methodology for the development of a customized virtual 3D shoe last has been developed. The point data cloud of a foot is obtained at certain critical regions. A set of certain crucial points are then obtained from this point data cloud. A set of normalized cubic splines are constructed through these points. The designer has the facility to modify the shape of the curve according to his convenience through changes in magnitude of tangent vectors. Coon's bicubic surface patches with required continuity constraints (C^0 ,C^1) are then fitted on this curve-network. Variations in the shape of these surface patches can be done by the designer through changes in magnitudes of twist and tangent vectors.

A technique for flat pattern development of parametric 3D surfaces, leading to nondistorted texture mapping, has been described. The technique is based on the results of differential geometry, more precisely on the notion of "geodesic curvature". Isoparametric curves of the surface are mapped in a constructive way, on a flat plane with preservation of geodesic curvature and arc length at each sample point. In this technique arc length between sample points are approximated by chordal length. This introduces a slight error, but the error can be minimized by increasing the density of mesh and bringing the sample points close to each other.

Two approaches have been considered for the development of doubly curved surfaces. In the first approach geodesic curvature preservation is done only in one parametric direction. In this approach error concentration grows on as one moves away from the initially selected curve. This makes the technique strongly dependent on the initial curve. In the second approach geodesic curvature preservation is done in both

directions along with relaxation technique to distribute distortions in a more distributed manner.

A program for flat pattern development of doubly curved surface is made in C language and is interfaced with I-deas (MS-6A), using its Open Architecture Module. Required input parameters are entered by the designer during the execution of the program. Any surface existing in I-deas can be directly flat patterned and the resulting developed surface is displayed on the I-deas graphics screen.

6.2 Suggestions for Future Work

1. How to reduce as much as possible the number of cut pieces chosen for development and also how to merge them appropriately is still an area to work upon.

2. The scanning of foot, which was done by the Faro Arm can be done optically by placing the camera's at certain fixed location with respect to the foot. The critical points of the foot can then be obtained directly from the scanned data by making appropriate algorithms.

3. In the present model of customized shoe last design normalized cubic spline curves and bicubic patches are used for curve fitting and surface fitting. These curves and surface patches can be replaced by Bspline curves and Bspline surface patches with more number of control points. This will provide the designer more flexibility to manipulate shapes of curves and surfaces.

4. The doubly curved surface can be approximated with a set of ruled surface. These developeble ruled surface can in turn be developed individually.

5. The initial curve for the development could be chosen automatically, it need not be chosen manually as it is done in present approach.

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